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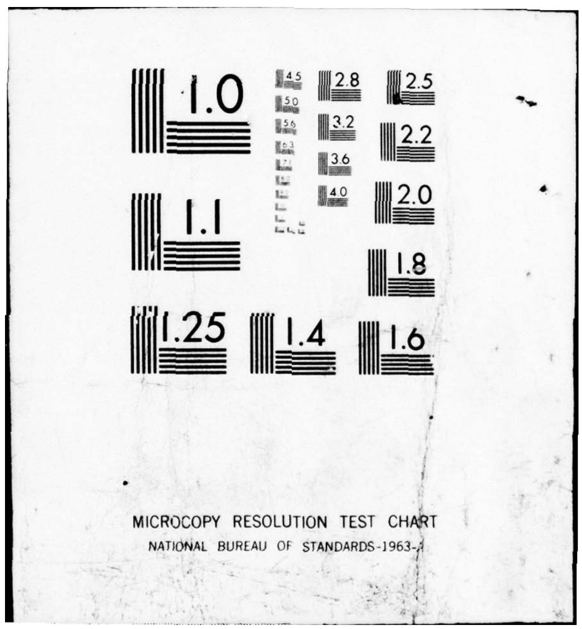
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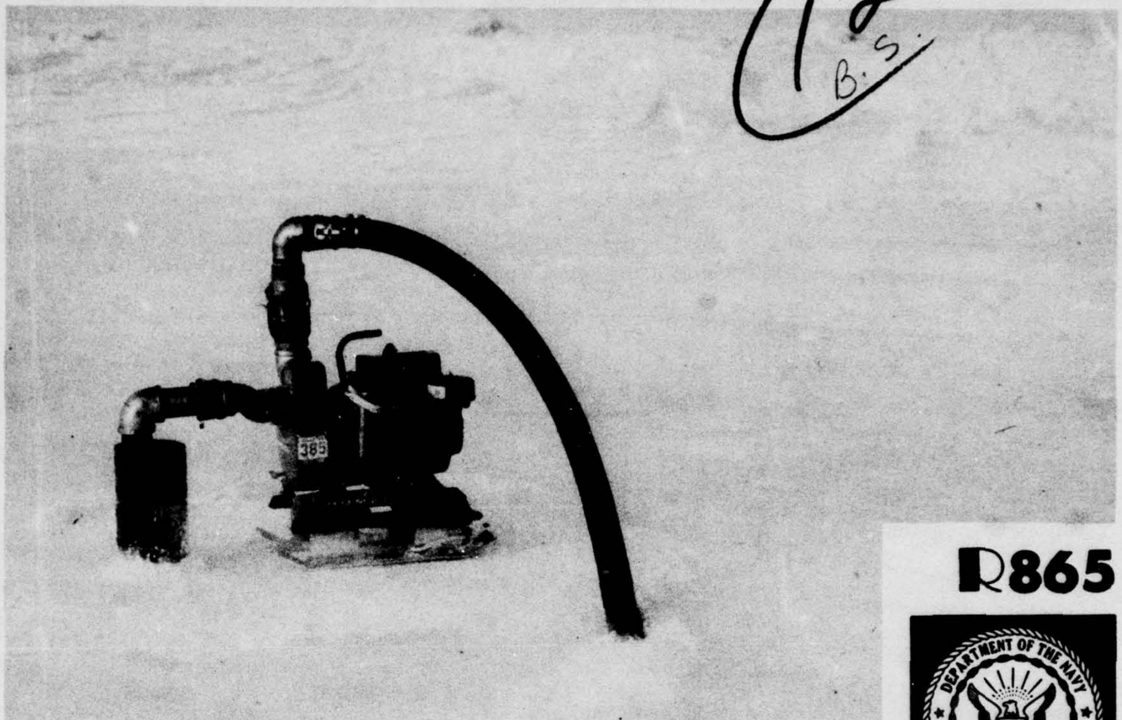

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TECHNICAL REPORT
CIVIL ENGINEERING LABORATORY

Naval Construction Battalion Center, Port Hueneme, California 93043

NANSEN DRIFT STATION PROJECT – REMOTE SEA-ICE RUNWAY CONSTRUCTION

by
J. L. Barthelemy

April 1978

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In the past, surface-flooding activities have been confined to areas near major military logistic centers. As a result, techniques developed for sea-ice runway construction relied extensively upon the use of heavy equipment to clear snow and position large stationary pumping equipment. At remote sites, such as that planned for the proposed Nansen Drift Station, requirements are different. Construction crews will be severely restricted as to their size and number of support equipment available, and they may be over

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INTRODUCTION

During March 1977, an engineering field team from the Civil Engineering Laboratory (CEL) conducted surface-flooding exercises on the annual sea ice near Point Barrow, Alaska. The purpose of those exercises was to evaluate candidate pumping equipment developed for the proposed Nansen Drift Station (NDS) project and to test some new techniques of surface flooding. The water-handling components included two modified, lightweight, centrifugally driven trash pumps that had undergone preliminary low-temperature testing in the cold chamber facilities at CEL. Both pumps were basic Homelite model 120 TP3-1A units, weighing 108 pounds (including engine) and rated at 385 gpm. Each pump was powered by an 8-hp Briggs and Straton 4-cycle gasoline engine. While one unit was tested with the original off-the-shelf recoil-pull starter, the other unit was refitted with a Briggs and Straton 12-volt electric starter-generator set up. Both pumps were mounted on lightweight aluminum skids for field operations. The weight of the complete electric-start unit, including generator, battery, skid, and inlet/outlet plumbing was about 210 pounds.

CEL had already developed equipment and techniques for surface-flooding technology. However, the requirements for the proposed Nansen Drift Station differ somewhat from those of past operations. Historically, the objective of surface-flooding projects in the Arctic, the Antarctic, and Greenland was to artificially accelerate the natural growth rate of a seasonal ice sheet and, thereby, effectively increase thickness and strength in a short period of time. It was necessary to provide stationary, high-volume pumps and large-scale support equipment. The logistics were accomplished without serious difficulty because past test sites were located near major military establishments. The NDS project, on the other hand, will be staged in a remote area of the Arctic where both manpower and support equipment will be seriously limited; thus, pump components should be restricted to a size and weight that can be handled comfortably by one or two men. Also, the proposed drift of the research platform will be through pack ice that should have sufficient thickness and strength to support aircraft. Surface flooding will be required more to repair and resurface the top of existing ice rather than significantly increase its thickness. For this task it will also be necessary to have lightweight, mobile and easily relocatable water-handling equipment.

This document considers the specific details involved in selecting, modifying, and testing the candidate pumping system for the NDS project. It contains a rather comprehensive Background section on surface-flooding technology in general, and specifically those techniques and

processes compatible with the requirements of the Nansen Drift Station program. Funding for this task work was provided by the Office of Naval Research as RDT&E assistance to the NDS project.

BACKGROUND

In the year 1893, Fridtjof Nansen sailed his ship the FRAM through the Barents Sea and into the Laptev Sea, where he inserted her in the pack ice. In less than 3 years, the FRAM drifted westward with the pack and emerged from the ice near Svalbard. Duplication of Nansen's scientific journey has been considered many times. The planned decommissioning of the WIND-class icebreakers by the U.S. Coast Guard offers an excellent opportunity to acquire a suitable platform to carry out a comprehensive research program in a little-known area of the Arctic. The proposed Nansen Drift Station project would be a multidisciplinary scientific program ranging from the study of plate tectonics to the measurement of the effects of high-energy solar particles on the earth's magnetosphere (Ref 1).

CEL was given funds to develop pumping equipment and techniques in December 1976 with a target "launch" date of late 1977 for the drifting platform. At that time, the icebreaker USCG BURTON ISLAND (Figure 1) was identified as the most likely candidate to be used in the project. It was recognized that, given normal ice conditions, the only time the vessel could begin a passive drift would be September or early October. Helicopters and small fixed-wing aircraft would be needed to provide logistic support between the icebreaker and remote field camps. Since the ship's existing tanks do not hold sufficient diesel and aircraft fuel to support an entire drift, it would be necessary to periodically shuttle in fuel by air from mainland logistic centers using long-range aircraft. Such long-range aircraft would also be required for personnel rotation and cargo resupply. The most desirable aircraft considered for resupply was identified in Reference 1 as the large C-130 cargo plane. For less favorable runway conditions, an alternate airplane would be the C-117 (Super DC-3), of which the Naval Arctic Research Laboratory (NARL) presently has two.

Subsequent to completing the Barrow field tests in March 1977, the decommissioning of the WIND-class icebreakers was delayed and, as a result, the Nansen Drift Station project has been postponed to some as yet unfixed future date. When it does come to fruition, there will be many logistical problems, a major one being that of maintaining an ice runway suitable for aircraft operations. By the very nature of the project, the drifting icebreaker will be placed in an area of intensive ice movement. It would be idealistic to try to maintain one permanent ice runway throughout the duration of the drift. Likewise, from the standpoint of time and manpower demands, it would be highly impractical to construct an entire 150 x 5,000-foot runway by surface flooding. Since the pack ice in the area of the research platform should be of sufficient thickness and strength to support aircraft, a better approach would be to select prior to each resupply effort two or more promising

sites where the ice is relatively uniform and devoid of irregularities, and then concentrate efforts on repairing specific problem areas. Hummocks and pressure ridges could be leveled by blasting and then flooded to a smooth finish; refrozen cracks and areas of rough ice could be glossed over by surface flooding to obtain a uniform surface. CEL used these guidelines in preparing the Memorandum of Procedure for the flooding exercises at Barrow.

It was planned, in addition to evaluating the performance of pumping equipment and flooding methods, to scout the offshore annual ice in the vicinity of Barrow for candidate "problem areas" and then practice methods of ice removal and repair by interfacing with a blasting team contracted through the Nansen Drift Station Project Office of the Division of Marine Sciences at the University of Washington. Before the specific observations of the Barrow exercise are discussed, the development of surface-flooding technology will be reviewed.

HISTORY OF SURFACE FLOODING

During the winters of 1950-51 and 1951-52, experimental work sponsored by the Bureau of Yards and Docks was conducted near Point Barrow, Alaska, to determine the feasibility of thickening natural ice sheets at a faster rate than occurs naturally. Sea water was pumped into diked areas on top of the existing ice sheet and allowed to freeze. This process was repeated until the average thickness of ice was about 17 feet, as compared with an average natural ice sheet thickness of 6 feet. Prior to summer breakup in 1952, several successful ski landings by small aircraft and wheel landings by Navy R4D and P2V-2 aircraft were made on the thickened ice. These landings indicated the potential utility of thickened sea ice bases in the Arctic Ocean. As a result, in 1955 the Bureau of Yards and Docks issued a manual on the construction of sea ice bases by flooding (Ref 2). However, that manual left a number of questions unanswered regarding the change in material properties and physical characteristics of flood ice as well as the short- and long-term load bearing capacity of a flooded platform.

In 1958, the Air Force issued a manual (entitled ICE AIRFIELDS) that was designed to provide personnel with scientific facts concerning the landing of aircraft on floating ice surfaces. It addressed itself to the problem of treating ice, especially sea ice, as an engineering material (Ref 3):

> "The use of ice as a material in any type of construction presents many problems because, under sudden high stress, ice may fracture like glass. Steady or gradually increasing stress may cause it to flow and deform like a viscous liquid. The bearing strength of an ice sheet varies with its structure, its salinity, purity and temperature, and with its underlying medium - air, water or unfrozen ground. The same piece of ice will change strength when exposed to changing environmental temperatures."

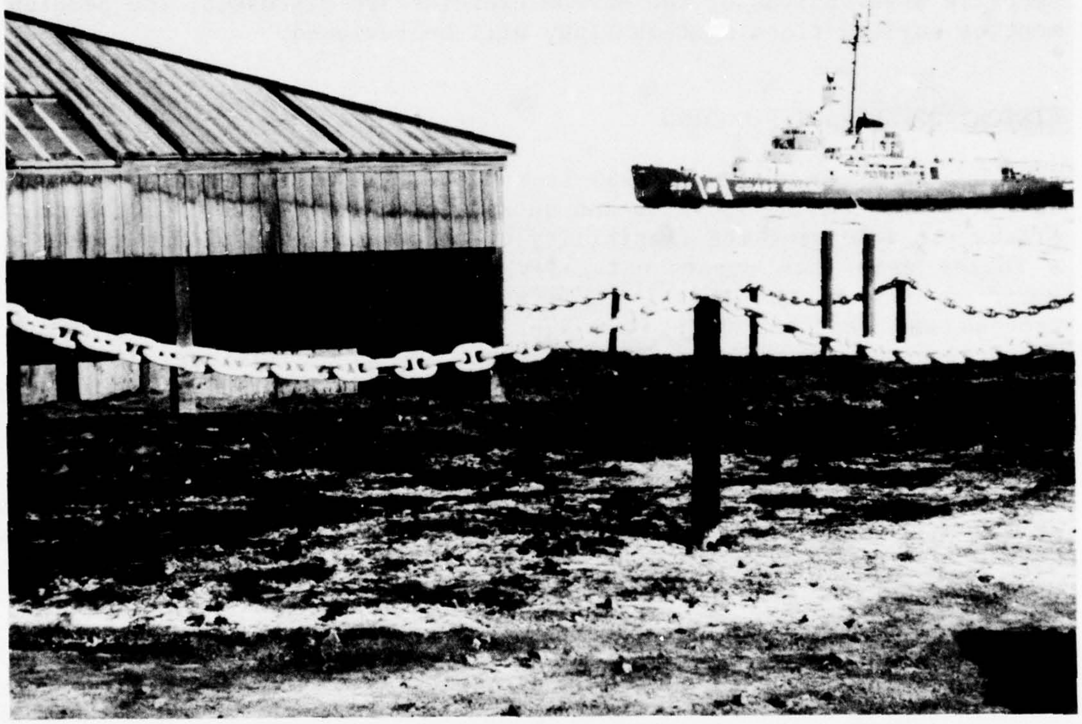

Figure 1. USCG BURTON ISLAND passing by Scott's Hut in Winter Quarters Bay, Antarctica.

That manual also pointed out the many advantages of using naturally occurring ice as a material for landing strips, and recommended further study of material and physical considerations.

During the winters of 1958-59 and 1959-60, personnel from the Naval Civil Engineering Laboratory* conducted further surface-flooding trials on the annual ice sheet near Point Barrow. The field teams were accompanied part of the time by investigators under contract to the Cambridge Air Force Research Laboratories. The objectives of the FY-1959 trials were (1) to investigate various construction techniques for improving sea ice and to study the physical properties of this ice; and (2) to functionally test the equipment developed for this type of work (Ref 4). For the FY-1960 trials the objective was to build a model ice platform by thickening an area of natural sea ice using free-flooding, a technique introduced during the previous winter's effort (Ref 5).

The first-year effort involved constructing seven test pads by confining flood waters within selected areas. (Figure 2 shows the layout.) For the most part, a 3-foot-high cheesecloth fence coated with frozen water spray was used as the diking material. All seven test pads were serviced by a centrally located pump-house consisting of a 1,000-gpm diesel-driven centrifugal pump inside a heavy-duty Navy wanigan (Figure 3). For reference, the weights of the pump wanigan and other accessory equipment used in that project are shown in Table 1. Construction of the individual pads was varied in terms of the incremental flood depth applied and freeze-back time to study the characteristics of different flooding schedules. Approximately 350 individual specimens of natural and constructed sea ice were obtained from 3-inch-diameter cores for determining comparative ice salinity averages and salinity and brine content profiles. Of that group, 240 specimens were also used for crushing and ring tensile strength test and density determinations. Data from these pads were analyzed in an attempt to determine (1) the effects of air temperature and wind on the rate of freezing; (2) the effects of air temperature and wind on the quality of ice; (3) the extent of brine and soft ice in the cast layers; and (4) the effects of short-term aging on quality and strength of ice.

One problem encountered with confined surface flooding is the tendency of the built-up ice to overstress and downwarp the underlying supportive ice sheet. The result is a thickness of ice that, in cross-section, is bowed out on the bottom surface and contains a dish-shaped depression on the top surface. Figure 4 is an idealization of that configuration. When confined flooding is carried out to a point where substantial deflection occurs, the flooded area will project as a platform in the center of a shallow-sloped depression. When this occurs, cracks which extend through the ice sheet may develop around the outside of the flood zone, and a natural flooding of the depression may occur.

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*On 1 January 1974 redesignated the Civil Engineering Laboratory (CEL) of the Naval Construction Battalion Center, Port Hueneme, California.

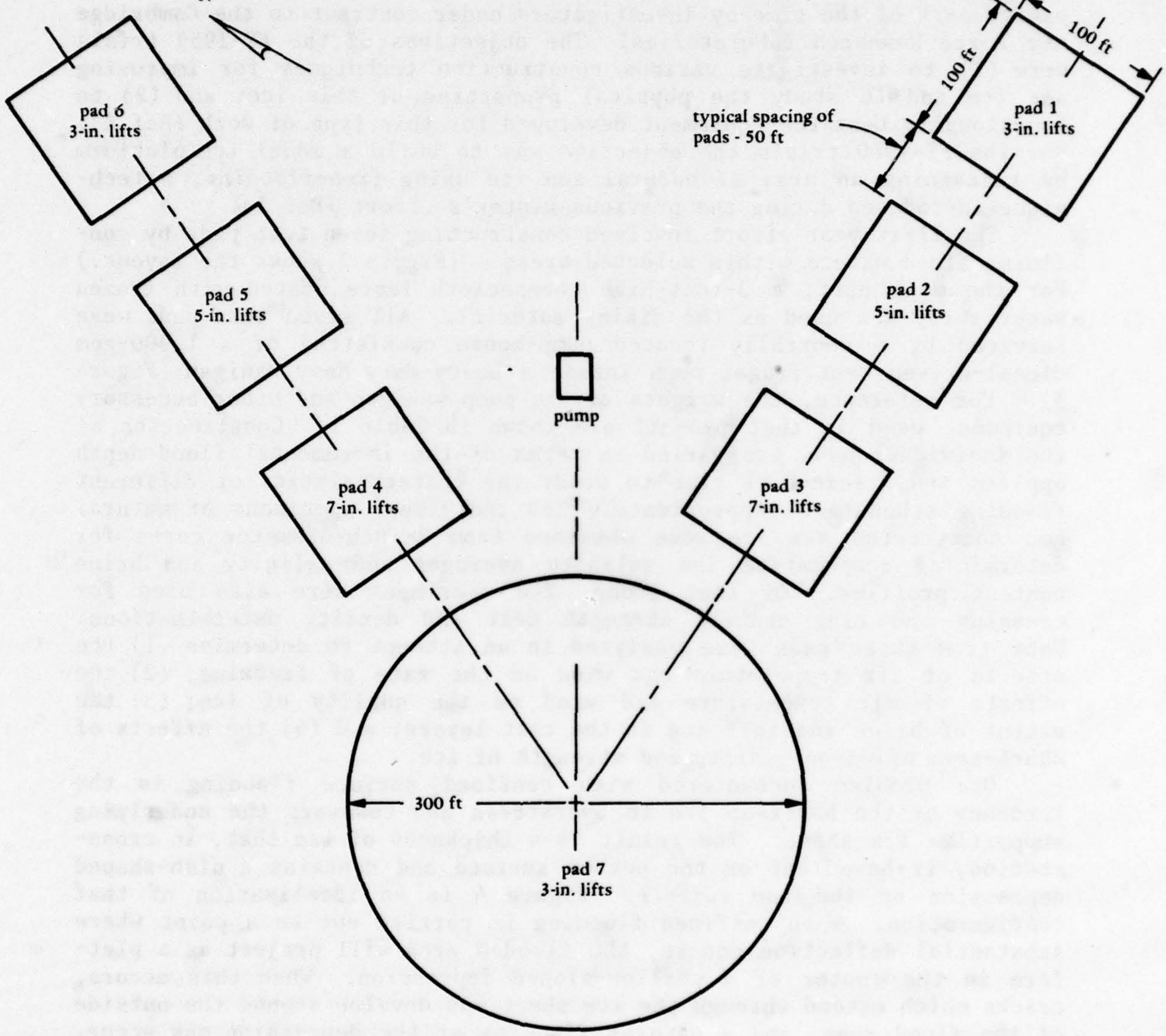


Figure 2. Field layout during the FY-1959 trials.

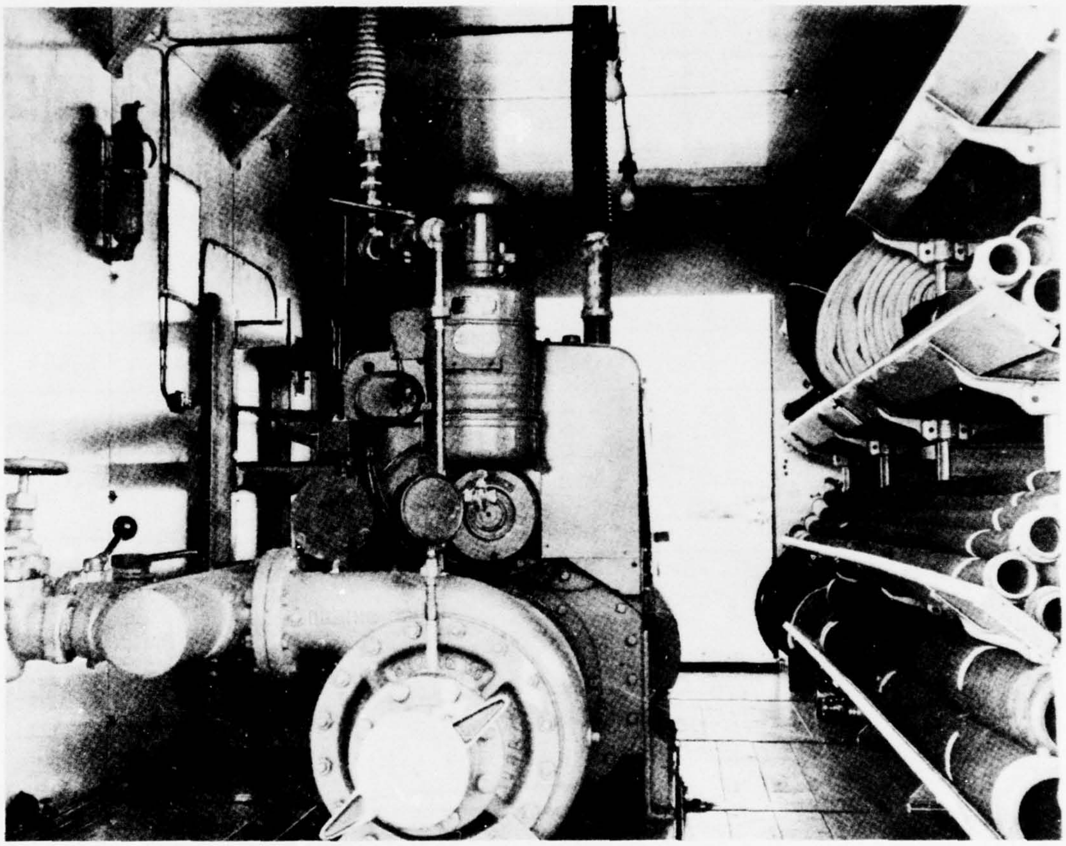


Figure 3. NCEL wanigan and 1,000-gpm diesel-driven centrifugal pump.

Table 1. NCEL Equipment and Material Airlifted to Point Barrow for the FY-1959 Trials

Item	Net Weight (lb)	Packages (no.)	Packaged Weight (lb)	Cube (ft)
Pump Wanigan	14,710	45	18,547	1,068
Utility Sled	2,650	1	2,650	293
Portable Ice Drill	162	1	222	16
Ice Test Equipment	347	4	454	25
Tools and Spare Parts	713	8	583	29
Misc Supplies	616	8	413	46
Total	20,435	71	24,496	1,654

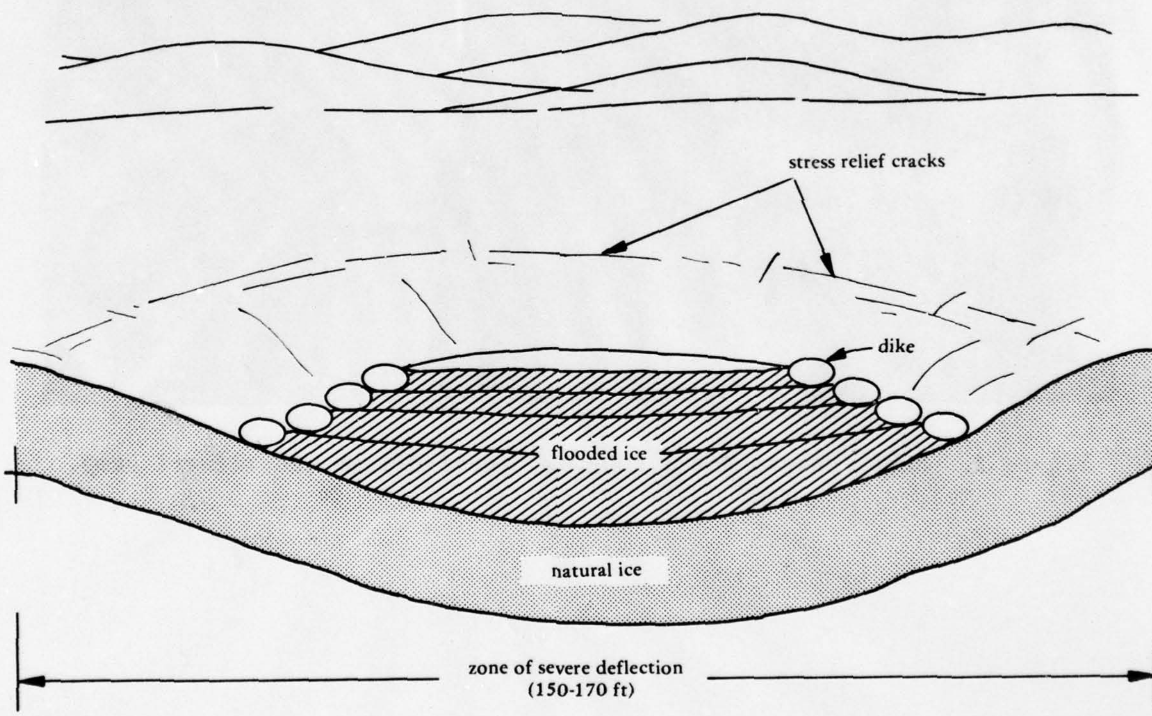


Figure 4. Typical section through 100-foot confined-flood area after construction.

Observations during construction of the FY-1959 test pads resulted in the concept of free-flooding. It was noticed that flood waters from a single point of discharge onto a flat ice sheet would produce a slightly dome-shaped mass of flood ice as long as the forward progression of the waters was not confined in any way. It was reasoned that the dome shape was the result of a continual damming action as the progression of the forward face of water was slowed and ultimately stopped by freezing, thereby backing up water. Further investigation during the second-year effort showed that free-flooding tends to produce a nearly flat surface even though the bottom of the ice sheet may be heavily deflected. Free-flood areas blend well with the natural ice sheet to produce thick areas convex on both the upper and lower surfaces. Figure 5 shows this free-flooding pattern.

During FY-1960, the second-year Point Barrow trials saw the testing of equipment and procedures for free-flooding. In addition to some of the materials used during the previous winter, two additional 1,500-gpm, medium-head, diesel-driven centrifugal pumps were shipped to the test site. These two units were placed 500 feet apart to provide an overlap of flood waters so that the finished test platform approximated the shape of an oval. Since the pumps were located in the flood zone to minimize the use of discharge hose and maximize the rate of water delivery, it was necessary to elevate the units above the flood waters and provide height for ice growth. That was accomplished by placing the pump stations on oil-drum support columns 5 feet above the surface.

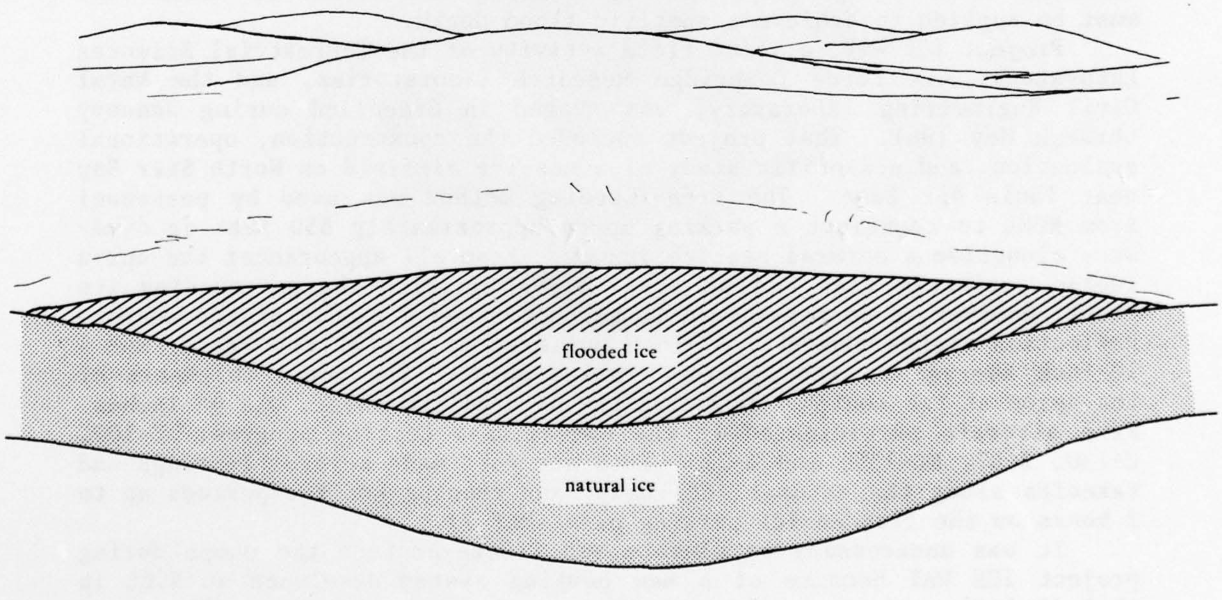


Figure 5. Typical section through free-flooded area after construction.

The greatest problem experienced with free-flooding was the presence of drifting snow on the flood plane. Snow picked up and carried by the moving flood waters tended to form a thick slush at the wave front, causing a more rapid slowdown and back-up of water. The result was a decreased flood-water radius and an increased water depth. The pumps also proved to be somewhat of a handicap to the operation, since it was necessary to constantly heat them (protection against the cold environment) and to provide a means of maintaining an open intake hole.

As a result of the Barrow trials, some general recommendations were issued regarding surface flooding. Reference 6 states that the selection of the flooding method is primarily dependent on the thickness of the natural ice and the thickness of the new ice to be constructed. When the ratio of the thickness of constructed ice to natural ice is small, no significant deflection of the natural ice will occur in large flooded areas. However, in most applications on thin ice sheets, free-flooding will be the most satisfactory method since a nearly flat ice surface is maintained even though the bottom of the natural ice sheet is heavily deflected. If confined flooding is used to a point where substantial deflection occurs, the surrounding natural ice sheet may be overstressed to the point of cracking around the outside of the flood zone. When flooding is performed on thick ice, it is generally done to improve surface characteristics rather than increase load-bearing strength. For ice 15 to 20 feet thick, confined flooding may be considered the more favorable method. Confined flooding is especially useful for the following applications: (1) building ice platforms of specific shapes; (2) retaining water in a specific area from which it would normally drain by gravity; and (3) reducing the amount of water that must be applied to achieve a specific flood depth.

Project ICE WAY, a joint field activity of the Terrestrial Sciences Laboratory, Air Force Cambridge Research Laboratories, and the Naval Civil Engineering Laboratory, was staged in Greenland during January through May 1961. That project included the construction, operational evaluation, and scientific study of a sea-ice airfield on North Star Bay near Thule Air Base. The free-flooding method was used by personnel from NCEL to construct a parking apron approximately 650 feet in diameter alongside a natural sea-ice runway. From all appearances the apron looked perfectly flat and at equal elevation with the surrounding ice sheet; however, a survey showed it to be crowned 6 inches at the center. Deflection stakes showed a 47-inch build-up of ice at the center and a 10-inch average at the 250-foot radius point. The total thickness of the apron at the center, including the natural ice sheet, was 94 inches. Five aircraft participated in the operational testing program: F-102, C-130, B-47, KC-135, and B-52. Each aircraft made several landings and takeoffs along the natural ice runway and then parked for periods up to 2 hours on the flooded-ice parking pads (Ref 7).

It was unnecessary to elevate and freeze-protect the pumps during project ICE WAY because of a new pumping system developed at NCEL in 1960 (Ref 8) - an experimental 1,600-gpm, 5-psi head, submersible pump. At that time there were no standard commercial units available that met the low-pressure, high-volume requirements for free-flooding. The NCEL submersible pump was assembled from standard components and consisted of

an 8-inch propeller-type irrigation pump coupled to a 7.5-hp, 1,800-rpm submersible motor mounted in a 16-foot-long, 16-inch-diameter casing. Electric heating elements were placed on the outer casing so that the pump could be removed from the ice. The submersible pump, which was light in weight compared to engine pumps of equal capacity, required no priming or winterization and could be left in place in the ice sheet until construction was completed. In terms of total system, the pump weight advantage was offset by the weight of the required electrical generator. But on the other hand, the generator was required for other functions. For the ICE WAY operation, surface flooding was carried out by placing the pump in the center of the parking apron. As a result of the success of that operation, NCEL later developed a family of these pumps for ice construction (Ref 9).

More recently, surface-flooding techniques have been used in the Antarctic to help solve ship-cargo problems. McMurdo Station, the major United States logistics base in Antarctica, receives the bulk of its supplies by vessel via shipping lanes into a small, sheltered body of water called Winter Quarters Bay. Since 1965, the annual sea ice has been cleared from Winter Quarters Bay each year so that ship cargo could be discharged directly onto the shore-fast ice that served effectively as an unloading dock. However, shipping operations resulted in extensive erosion of the fast-ice face. A protective dock facing was fabricated along the shoreline from structural steel and piles, but it was destroyed by storm in early 1972. Since then, surface flooding has been used as an effective method of extending the natural fast-ice wharf (Ref 10).

Late in 1972 crews at McMurdo Station built an experimental "ice cube" by surface flooding an enclosed 25 x 50-foot section of annual ice along shore. The so-called ice cube was used as a ship-to-shore fender to complete cargo offloading operations in January 1973. During the following austral winter, a much larger second-generation surface-flooded ice structure was completed. Dimensions included a 460-foot seaward face, a 635-foot backside boundary and a width of nearly 170 feet. Although the large structure was fractured into several pieces by an icebreaker attempting to clear Winter Quarters Bay of sea ice in January 1974, it nonetheless served as an effective docking facility until early 1976 (Ref 10). Figure 6 shows the USNS MAUMEE against the structure in February 1974.

In late 1975, CEL was charged by the Naval Support Force Antarctica (NSFA) with the task of providing design criteria, construction procedures, and pumping equipment for a larger, more completely engineered, third-generation surface-flooded ice wharf. That structure was subsequently completed during the 1976 austral winter and was used during ship operations in January and February 1977. The general layout, as pictured in Figure 7, includes overall dimensions of approximately 825 feet along the seaward face and 300 feet along the side face. Within the larger area, a smaller 500-foot-long, 200-foot-wide area was reinforced using two layers of 1-inch-diameter steel cable placed in an overlapping, closed-loop configuration near the neutral axis of the structure. The reinforcement was included mainly to tie the wharf together should cracking occur, rather than to increase its strength.

The large size of the ice wharf should prove to be an asset. It extends into waters deep enough to handle the draft of all visiting ships, and is long enough to moor these ships alongside. In addition, there is enough dock space for easy cargo off-loading and a steady flow of vehicles (Ref 11).

Flood waters were delivered to the second-generation ice wharf from three gasoline-driven engine pumps located in protected shelters on the sea ice outside the perimeter of the flood zone. As a result, a considerable number of man-hours of labor were used in servicing and repairing pumps, maintaining pump houses, and preserving open intake holes through the annual ice. In addition, extra personnel were required to relocate long runs of discharge hose and to thaw the hose which tended to freeze up.

The procedures and equipment developed by CEL helped avoid some of the problems encountered during the second-generation construction. The two pumps provided for the third-generation effort were both 1,500-gpm submersibles patterned after the units operated in Greenland. The two pumps were designed and assembled at CEL. During construction, they were permanently located within the bounds of the flood zone and required no priming or winterization. It was necessary, however, to re-elevate them periodically as the flood-ice grew to the limits of the discharge height. That was easily accomplished by activating the electrically traced heat tape located inside the outside casing. No discharge hose was used so that, for the most part, the flooding procedure was as simple as turning on and off the pumps once a day and scouting the flood zone to ensure an even distribution of water. Figure 8 shows a cross section of one of the pumps that measured 12-1/2 feet in overall length and 19 inches in diameter and weighed 1,000 pounds. The lower end of the unit consists of a propeller pump coupled directly to a 7.5-hp, 240-volt, 3-phase, submersible electric motor.

Another improvement was the provision of methods for obtaining a smooth and vertical seaward face for docking. During construction of the second-generation wharf, great care and many man-hours of labor were spent in building the outward-facing flood-water containment wall. Wood forms (later removed) were filled with a snow-water slush which upon freezing formed a rigid boundary. It had been hoped to achieve a well-defined transition between the flooded-platform and the sea ice so that the annual ice could be smoothly sheared from the outward face during ice clearing operations in Winter Quarters Bay. In spite of those efforts, some of the cracks induced in the annual ice by icebreaker movement propagated through the ice wharf, fragmenting it into several well-defined pieces. The following season, in January 1975, a field crew from CEL used a trencher modified for NSFA to cut the annual ice outside the seaward face of the wharf just prior to icebreaker operations, thus creating a buffer zone against crack propagation. As annual ice was then fragmented and cleared, blasting was used to create the desired vertical face. The present-day third generation ice wharf was constructed with a nonreinforced, 200-foot-wide frontal area to accommodate several years of trimming of the seaward face. Because a vertical face was not a construction requirement, it was possible to erect simple pushed-up snow walls by bulldozer to contain flood waters.

Figure 6. USNS MAUMEE docked against ice wharf in Winter Quarters Bay, January 1974.

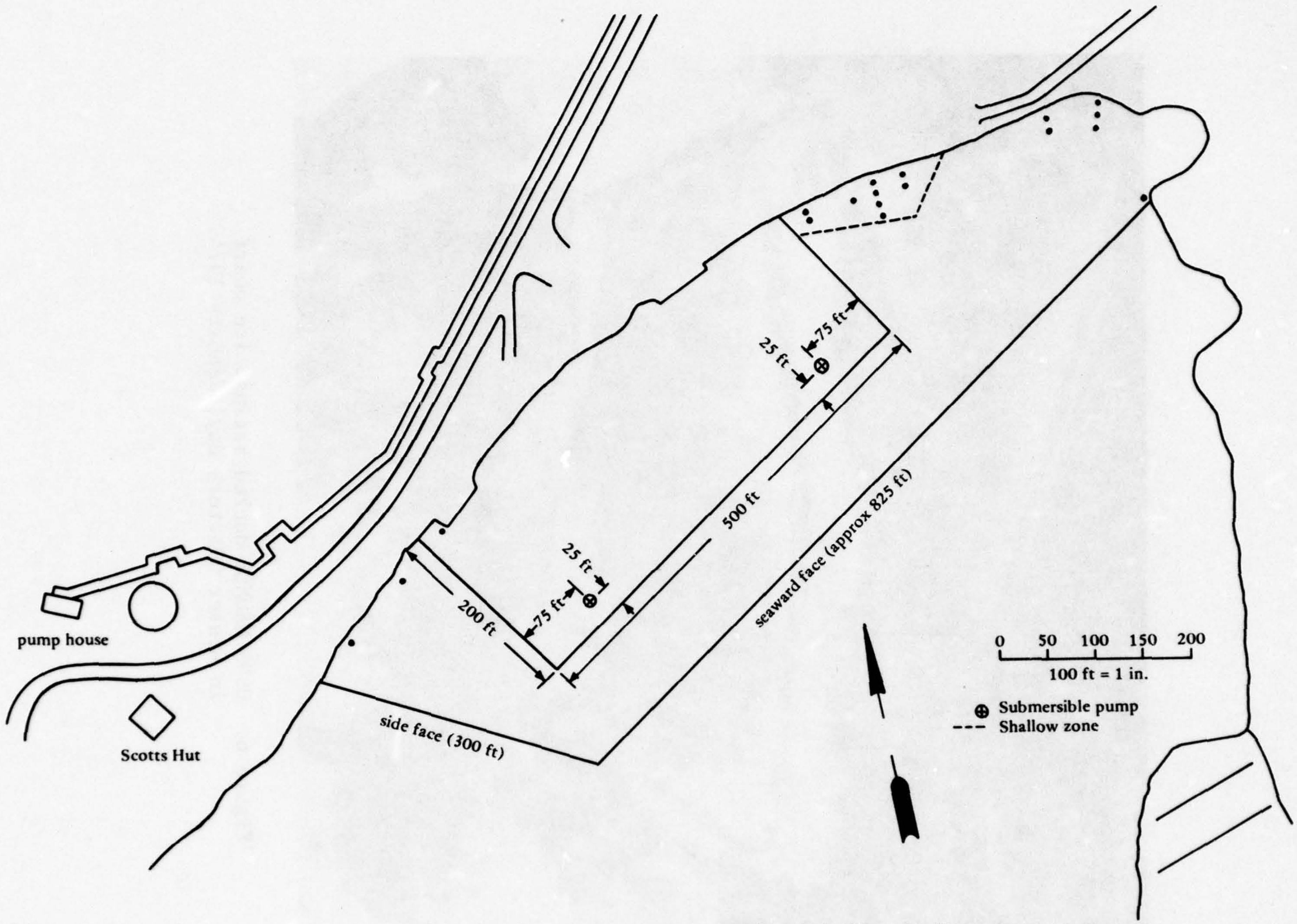


Figure 7. Layout of ice wharf built in Winter Quarters Bay during 1976.

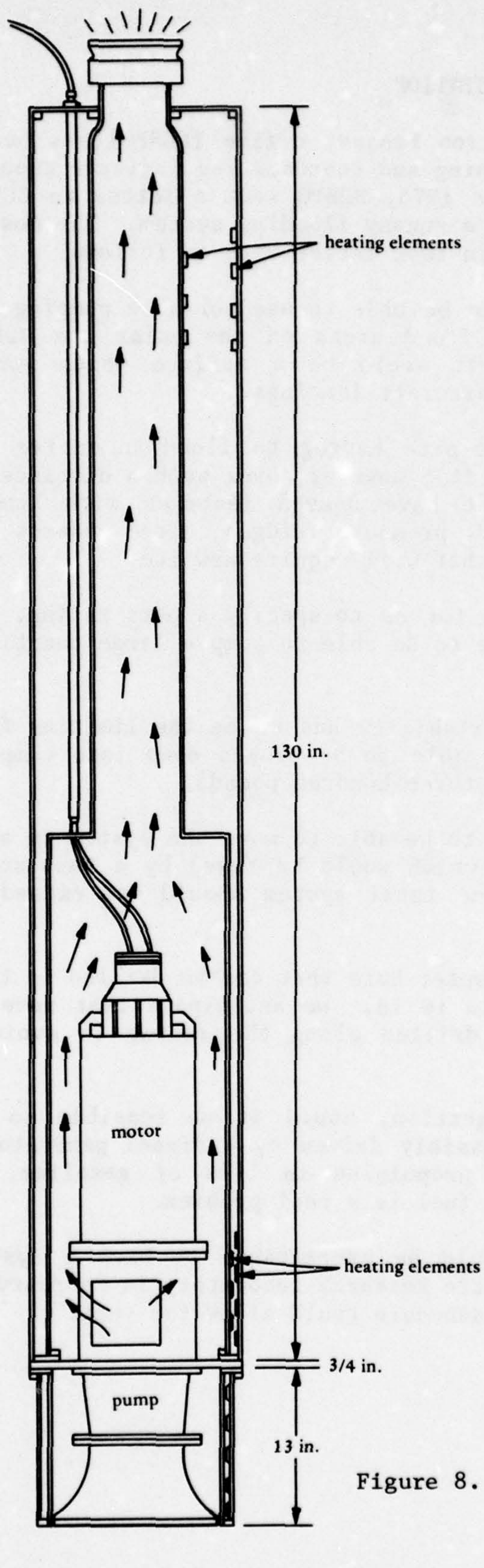


Figure 8. CEL-developed submersible surface-flooding pump.

CRITERIA FOR NANSEN DRIFT STATION

The Nansen Drift Station Project Office (NDSPO) has been assigned the responsibility of planning and coordinating logistic support for the NDS project. In September 1976, NDSPO sent a letter to CEL outlining the basic requirements for a runway flooding system. The most important design criteria contained in that letter were as follows:

> "We would like to be able to use portable pumping system with which we could flood areas on the polar ice with sea water. The end result would be a surface which would be suitable for wheeled aircraft landings.
>
> "We do not anticipate having to flood an entire runway (say, 150 ft by 5,000 ft); however, over such a distance there may be stretches that have uneven features with hummocks, cracks after removed pressure ridges, free boards after refrozen leads, etc. that will require new ice.
>
> "It is difficult for us to specify a pump rating, but of course it is desirable to be able to pump a large quantity per time unit.
>
> "However, the portability has to be the limiting factor. The system should be able to be broken down into components weighing no more than three hundred pounds.
>
> "It is desirable to be able to move the system on a sled, i.e., a Nansen sled, which would be towed by a snow scooter. Maximum weight for the total system should not exceed 1,000 lb.
>
> "The maximum diameter hole that can be drilled in the ice with minimum effort is 10 in. We anticipate that several of these holes will be drilled along the runway to avoid long hoses.
>
> "Just as a suggestion, would it be feasible to use a submersible pump - possibly driven by a diesel generator? We would prefer diesel propulsion in lieu of gasoline, since storage of the latter fuel is a real problem.
>
> "Finally, it would be preferrable to have a system to test at the Naval Arctic Research Laboratory in February 1977. Hopefully, your time schedule could allow for that."

Analysis of Requirements

The type of surface flooding required for the Nansen Drift Station project would be different from the surface flooding practiced during previous operations. The work in Alaska, Greenland, and Antarctica all required substantial flooding of natural sea ice to increase thickness and strength. To accomplish those tasks, it was necessary to use large, high-volume pumping equipment and substantial numbers of support personnel. Each of those sites was conveniently located near an established military logistics center where workers were billeted and messed and equipment could be shipped, staged, transported on-site, and serviced. Once installed, pumping equipment was almost invariably permanently located until the end of construction.

The Nansen Drift Station, on the otherhand, will be staged in a remote area of the Arctic, far from any large support base. It will be foremost a scientific effort; thus, the support force on board will probably be limited as to numbers and hours available for runway construction. Also, one should anticipate a shortage of vehicles for on-the-ice logistics. One criterion states that the pumping system should be provided as components capable of being transported by sled and snow scooter. It would be convenient to have treaded cargo/personnel carriers and a light-weight bulldozer available to move snow and haul equipment, but such a situation should not be anticipated because of pressing priorities and breakdowns. Thus, concepts for surface flooding at the Nansen Drift Station should consider weight and portability as limiting factors.

Actually, the special requirements for a runway at that remote site favor such a system. The passive drift of the research platform will occur in the permanent ice pack, which should already have sufficient strength and thickness to accommodate long-range wheeled aircraft. It will not be necessary to deposit large volumes of seawater over an entire runway site; it would not even be practical to do an entire runway. Rather, as currently envisioned, surface flooding will be used in specific problem areas to pave a small part of an otherwise usable runway. It may be necessary to shutdown and relocate a pump several times in a single day; thus, it should be easy to remove and transport.

Although diesel fuel is the major fuel supply planned for the NDS project, the idea of using a diesel engine directly coupled to a pump was dismissed early in the analysis. At the present time, there are no diesel-engine pump units produced in this country that come close to the 300 pounds per component weight limitation. More importantly, as later pointed out, snow scooters and very likely other equipment will require gasoline, so provisions must be made for its storage and distribution. Similarly, the use of pumps powered by electric motors was also dismissed.

In terms of pump output per pound of system weight, it becomes very unfavorable to use either diesel- or gasoline-powered generators to power motor pumps because of the appreciable loss in overall operating efficiency in going from engine-to-generator-to-motor-to-pump. There is also a loss in portability and flexibility - portability because the

number and weight of components to move and relocate are increased; flexibility because the pump must be located near a generator. In past operations, the greater ratio of pump weight to pump output for electric propulsion was usually more than offset by the fact that multiple pumps and auxiliary equipment could be operated from a single generator. Also, electric submersibles could be installed on a long-term basis because of their built-in winterization and priming features, thus greatly facilitating operation. Runway construction for the NDS project, on the otherhand, will require constant relocation of pumps at a number of different points along a potential site or sites; thus, it would be very difficult to use a single generator for all units and impractical to provide a generator for each unit. It would be very convenient to use shipboard power, but there can be no guarantee that a potential runway site will exist within a distance reasonable for placing power cables.

As seawater is pumped onto the surface of a flooded pad, it undergoes little change in elevation - basically just the freeboard of the ice sheet. Thus, there is very little pressure head generated when no discharge hose is used. As hose is added to the system, there may be an appreciable pressure drop, resulting in reduced flow. This situation is especially true when ice forms in the hoseline. However, it is predicted that, for the most part, short runs - less than 50 feet in overall length - will be used. Hose at any temperature is bulky to transport and hard to handle; hose at subfreezing temperatures easily freezes up and is difficult to thaw. In addition, flow rate decreases as hose length increases. It is easier to relocate a lightweight, portable pump than it is to fight hose. Therefore, the major requirement for pump performance at the Nansen Drift Station would be high output volume rather than high pressure head.

Pump Selection

The class of pumps with the greatest ratio of gallons per minute output to pounds of total weight is the gasoline-engine-driven centrifugal pump. These units produce a high volume at a relatively low head. The centrifugal pumping principle consists, essentially, of an impeller arranged to rotate within a case so that the liquid will enter at the center, be thrown by centrifugal force to the outer periphery of the impeller, and discharged into the outer case. Figure 9 shows the volute-type centrifugal pump that converts the velocity energy of the liquid into static pressure at the discharge connection.

Table 2 presents some design data for a number of commercially available gasoline-engine-driven centrifugal-type pumps. The unit with the greatest output/weight ratio, the Homelite model 120 TP3-1A, was ultimately selected for the project. Strictly speaking, this unit is a self-priming, volute-type trash pump. Trash pumps operate in the same way as do pure centrifugals, differing only in the size of clearances. The larger clearances of the trash pump allow small particles, such as gravel and ice chips, to pass through without damage to the impeller. This feature was thought to be an advantage for the intended usage. The

model 120 TP3-1A is self-priming to the extent that it can be shut-down and re-started repeatedly without risk of "losing prime," so long as the casing is filled initially. Of course, in subfreezing temperatures, water cannot remain in a non-running pump for extended periods of time or it will freeze and in all likelihood crack the pump casing. Under such conditions, it is necessary to drain and reprime prior to each usage. As an additional plus feature, the Briggs and Straton engine used to power the Homelite pump can be fitted with an optional 12-volt electric starter-generator kit. The Gorman-Rupp model 83A, which was otherwise competitive in terms of performance and cost, did not have that option.

Freezing Rates

During the winter months in the Arctic when construction by surface flooding is feasible, seawater is at the freezing-point temperature (Ref 12). When a single layer of cold water is cast on top of a "virgin" ice sheet, heat is transferred from the water down into the cold ice and up into the ambient air, causing an upward and downward growth of ice. These two processes take place simultaneously and independently until the flood-water layer becomes completely solid. It can be shown, however, that successive repetitions of the process will effectively remove the "cold storage" of the ice sheet by heating it until it attains a near-linear 29F temperature profile*. After that occurs, additional flood water will freeze almost entirely from the top as heat is lost to the cold air. As part of the FY-1959 Barrow trials, studies were conducted to check the effects of wind and air temperature on freezing. Not surprisingly, the following qualitative observations were confirmed: the growth rate of flood-water ice increases with increased wind speed and decreasing air temperatures. Subsequent experience in the field led to the following recommendations (Ref 6):

(1) The depth of water applied to any point should not be greater than that which will freeze through in 24 hours. This is about 4 inches of water at temperatures from 0F to -10F with moderate wind.

(2) A cooling period equal to the freezing period should be allowed before an ice area is reflooded. Such cooling is necessary for restoration of ice temperature and recovery of ice strength.

(3) Additional water should not be applied until all areas of the previous flood have frozen solid. The premature reflooding of an unfrozen area is very undesirable since the freezing time increases exponentially with depth.

*The freezing point temperature for seawater is 29F.

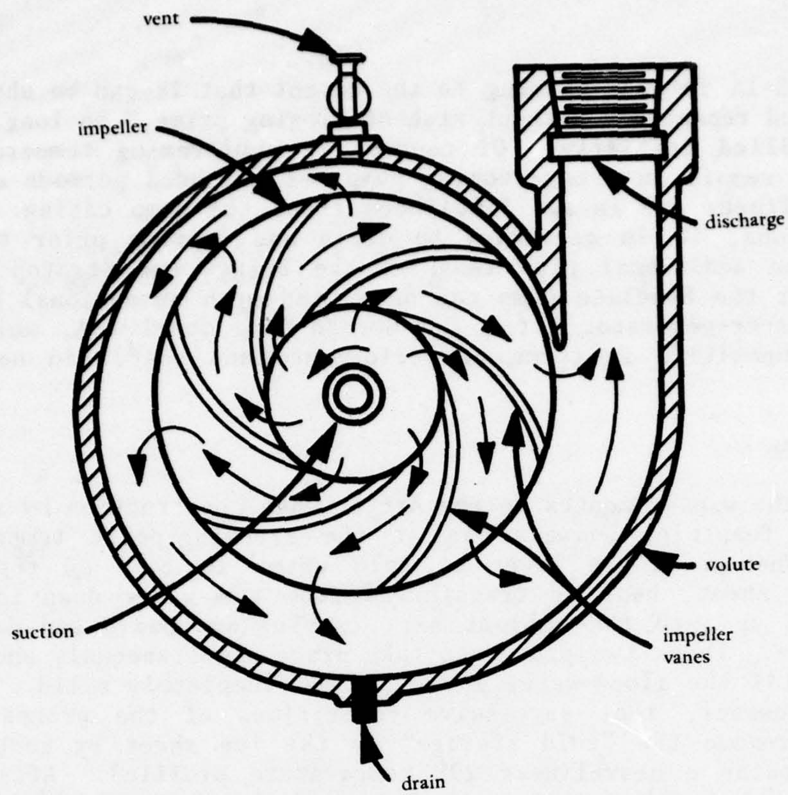


Figure 9. Pictorial view of volute-type centrifugal pump.

Table 2. Centrifugal Pump Specifications
(1977 data)

Manufacturer	Model Number	Price ($)	Flow (gpm)	Weight (lb)	Flow/Wt Ratio
Homelite	120 TP3-1A	645	385	108	3.6
Gorman-Rupp	83A	570	370	107	3.5
Homelite	9 TP3-1A	700	385	113	3.4
Berkeley	B3TQMS-12	712	600	245	2.5
Barnes	18ACG-1	663	260	115	2.3
Homelite	123 TP4-1	1,100	610	299	2.1
Berkeley	B2-1/2TQMS-12	742	450	235	1.9
Gorman-Rupp	13A2	1,220	400	290	1.4
Barnes	26 CCG 3	1,200	440	330	1.3

These provisions were established to guarantee enough time between floodings to let the flood water freeze and recharge some of the lost "cold storage" to the ice sheet. However, it is not always possible to maintain such a schedule. In building the ice wharf at Winter Quarters Bay, for instance, it was necessary to flood on a near-daily basis to obtain the design 20-foot ice thickness in a single season. For that project, the minimum standard was taken as provision 3 above. This implies that on a daily basis the combined time required to apply and freeze flood water should not exceed 24 hours.

Qualitative field observations confirmed ice growth to be a function of air temperature, wind speed, and elapsed freeze time. The following formula expresses quantitatively the functional relationship between these variables for a layer of 29F seawater freezing from the top down (Ref 13).

$$x = \frac{h\,\theta\,t}{325}\left[\frac{1}{1 + \left(1 + \frac{h^2\,\theta\,t}{4,500}\right)^{1/2}}\right] \qquad (1)$$

where x = ice thickness (in.)

t = elapsed freeze time (hr)

θ = the number of degrees Farenheit below 29F

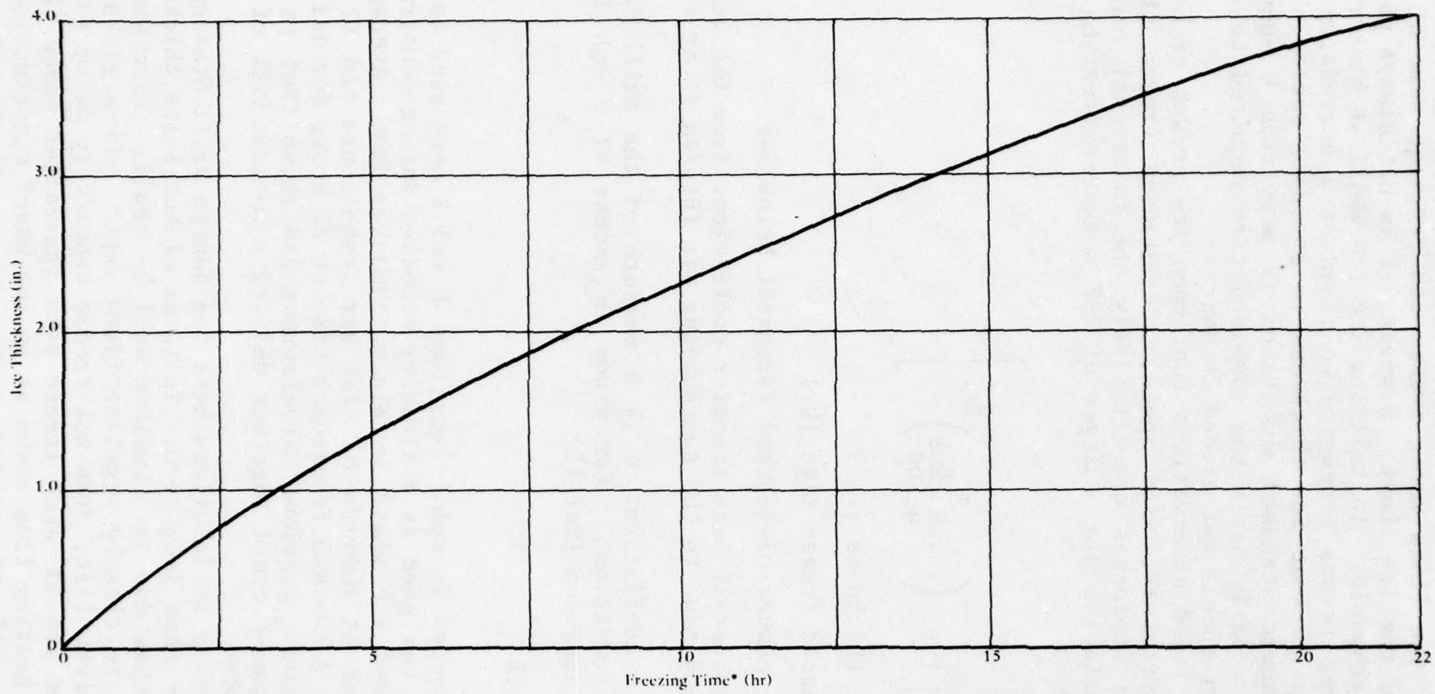
h = the overall heat transfer coefficient from the top of flood zone to the surrounding air (Btu/sq ft hr F)

The heat transfer coefficient h is a measure of the chill factor and depends on wind conditions. For winds in excess of 5 mph it can be estimated by the equation (Ref 13)

$$h = 0.62V^{0.8} \qquad (2)$$

where V is wind speed in mph. Equations 1 and 2 were used to generate Figure 10, which was used as a flooding schedule during construction of the surface-flooded ice wharf in Winter Quarters Bay. Average winter weather conditions at McMurdo of -13F air temperature and 12 mph wind speed were used. A maximum freezeback time of 22 hours for daily operation was used, since previous calculations had shown that in a 2-hour period the two pumps could together deliver a 4-inch lift of seawater over the flood zone.

Surface flooding at locations near the Nansen Drift Station will be short term rather than long term. In terms of total ice thickness, the incremental addition due to flooding will be small. Therefore, it is not so important to closely regulate flood depth. If a given layer of water, say the first lift, does not freeze completely prior to the next flooding, chances are it will freeze soon thereafter since there will not be prolonged heating from above as in ice wharf construction. Also, since for this application the base sea ice is thick and relatively



*Based on average winter weather conditions.

Figure 10. Flood depth as a function of freezing time for ice-wharf construction in Winter Quarters Bay.

unheated, it should provide pretty good heat sink characteristics for cooling from below. This is not to say, however, that a given location should be overflooded. It is never a good policy to deposit too much water in any area. One runs the risk of "breaking through" the flood layer if it is not completely frozen or causing localized downwarping of the surface.

Salinity

The formation of an ice cover on the surface of the sea is a refining process in which most of the salt is rejected. However, the freezing rate is usually too rapid for the rejection to approach completion, because the growing ice crystals trap a certain amount of brine. The quantity trapped is a highly variable function of freezing rate. If the ice cover is broken in the Arctic and seawater is exposed to air temperatures of around -30F, the first ice formed may have a salinity as high as 20 ppt. However, for a cover of annual ice a typical average figure is on the order of 4 to 5 ppt (Ref 14).

When seawater is cast on an already existing ice sheet, it is more difficult for the salts to escape. One characteristic of flood-water ice is a higher salinity level than undisturbed annual sea ice. During the FY-1959 trials at Barrow, 350 individual cores of natural and constructed ice were tested for salinity. The overall results showed a grand mean salinity of 16.8 ppt for flood ice and 6.4 ppt for the undisturbed ice sheet, an increase of 2-1/2 times. Similar tests in Greenland produced overall salinity averages of 10.9 ppt for flood ice and 4.8 ppt for natural ice. It is interesting to note that although the salinity of flooded material was 2 to 2-1/2 times that of natural ice, it was still just 1/2 to 1/3 that of seawater (average salinity 35 ppt).

It is also interesting to note that there was no appreciable increase in salt content in the natural ice sheet below the flood layers, thus implying that there was a migration of brine away from the ice sheet. Some brine escapes from the top of a flood-ice sheet; however, most of the salts escape through brine channels into the seawater below by two processes: drainage and migration. Drainage is a gravitational loss through small channels and is quite rapid when ice approaches the melting point. At colder temperatures, migration due to small differences in concentration is the dominant process. Consider an entrapped brine cell and the usual temperature condition, namely that the ice-air interface is colder than the bottom of the ice sheet, which is fixed at the freezing point of seawater. Because of diffusion, the concentration of brine within the cell will be uniform and of a salinity to match the mean temperature of the ice surrounding the cell. Thus, at the warmer end, the brine is too concentrated and will dissolve ice to reduce its concentration. At the colder end, more ice freezes to increase the brine concentration, and the net effect is to move the entire cell of brine along the gradient. This effect was demonstrated in a striking fashion by Whitman in 1926 when he forced brine to migrate upwards against gravity by applying a large vertical temperature gradient.

As brine content increases, the flexural strength of sea ice decreases. This characteristic may be an important consideration in sea-ice runway construction. In the case of the Nansen Drift Station, however, strength will be provided by the thick, low-salinity polar-ice foundation, and surface flooding will be used only as a finish paving. Of more importance than a potential decrease in strength is the surface condition resulting from the brine that does escape upward. A newly flooded area is usually covered by a very slick salt residue that, if persistent, could cause problems with aircraft landing. However, it has been the experience of the author that, in the cold, the film changes into scattered clusters of very small brine "flowers" that are not slick and should pose no problem.

PRELIMINARY TESTS

Two Homelite model 120 TP3-1A pumps were purchased, one with a standard recoil-type pull starter and the other with an electric starter-generator unit. A remote pushbutton starter switch was added to the electric unit at CEL. Tests were performed during early February 1977 in the large indoor cold-chamber facility at CEL to get a feel for pump performance at low temperatures. A flexible exhaust hose was connected from the muffler of each pump to outside the building, but even in this configuration it was not safe to operate the units for extended periods of time. Thus, the tests were confined mainly to checking start-up and short-term freeze-up characteristics in the cold.

Cold Start-Up

Before the pumps were placed in the cold chamber, the crankcases were filled with CONOCO Polar Start oil, a petroleum-based oil that is chemically restructured so that there is much less of a viscosity increase at low temperatures. The cold-soak start-up tests involved holding the two units for at least 24 hours at ambient air temperatures of 0F, -10F, and -25F. At the warmer setting, the electric-start unit consistently fired and ran immediately while the recoil unit tended to start on the fourth pull. At the intermediate -10F setting, the electric unit again started immediately. The second unit started after the eighth pull; however, it was noticed that the recoil cable retracted at a slower rate than for the warmer temperature. At the -25F temperature, the slowdown was so pronounced that it took over 15 seconds for the cable to retract fully. Thus, it was not possible to give the recoil starter a series of quick pulls for starting. It was thought that either the crankcase oil was too viscous (which should not be the case for Polar Start at -25F) or that the grease in the recoil-spring return unit was too thick. (Later in Barrow the recoil unit was disassembled, cleaned, and regreased with Polar Start oil. The problem of slow recoil return was then removed.) The electric-start pump also would not fire at -25F, even though the Briggs and Straton engine appeared to turn over at speeds fast enough for ignition. It was determined that the intake

air was too cold. When hot air from a 110-volt, AC-powered heat gun was directed toward the air filter and carburetor intake for 30 seconds, the unit fired and ran immediately.

As a final cold-soak test, the chamber was taken to its lowest operating temperature: -42F. At that setting neither pump would start unassisted. Heat had to be applied to the recoil starter for 4 minutes (until the cable retracted freely) and then to the air intake for another 3 minutes in order to start the pump with considerable pulling. The electric-start unit started after 2 minutes of heating the carburetor and intake. It became apparent that some means of applying heat in the field would be needed, but the use of a heat gun would not be practical since it requires 110V AC current.

Freeze-Up Characteristics

Tests were also conducted to determine the freeze-up characteristics of the pumps at low temperatures. The 1,500-gallon tank in the cold chamber was filled with freshwater that was then chilled to the 32F freezing point. As a first test, the electric-start pump was used to remove and return water to the tank for 2 hours in -15F air temperature. At the end of that period, there was no ice build-up in either the intake or discharge plumbing, or the pump casing.

When the test just described was first started, the cold pump was primed with ambient (near 70F) water, and there was no problem with operating the unit. For the next test, some of the chilled 32F freshwater was used for priming to simulate conditions anticipated for NDS (where 29F seawater will be used). Again the electric-start unit was used. The result was immediate freeze-up; the Briggs and Straton engine was not able to rotate the pump at all. At that point, the casing was quickly emptied of water (the units have a drain plug at the bottom of the casing) and the pump removed from the cold chamber. When the outer housing was removed, one could see ice around the impeller which had served as a very effective cold sink in freezing the already chilled priming water. After that test, it became policy to start the pumps first and then let them idle while filling with cold water. Strictly speaking, the pumps should not be run dry because the carbon-ceramic seals used will overheat and wear due to friction. However, for the short time required for priming and at the very low temperatures anticipated for operation, the tendency for seal wear should be minimal.

For the next test, the pump was primed with chilled water and allowed to idle for 2 hours with the discharge plumbing disconnected and capped. The chamber was held at -20F. It was desired to see whether the rotating impeller would impart enough energy to the cold water to prevent freezing. After a 2-hour period, the pump was drained and the housing opened. Not only was there no build-up of ice, but the water was actually heated to 56F as a result of the churning action. This observation was later used during the tests at Barrow. In the field, at the end of a pumping operation, both the intake and discharge plumbing were disconnected with the unit still running. The discharge was then capped and the throttle set at near full for several minutes. The

result was heating of the water and subsequent melting of all ice in the casing and drain. As one final step, after the pump was completely drained, the engine was turned over several times. In this way, the film of water adhering to the impeller shaft was flung away and freeze-up of the impeller was avoided.

SHOP PREPARATIONS

It was necessary to provide some means of elevating the pumps. In surface-flooding operations, it is not unusual to apply 3 or more inches of water to the ice sheet around a pump. It is also necessary to sometimes move the pumps through the flood zone and over surrounding snow cover. It was decided to design a skid system that would serve to both raise the pump and facilitate towing or dragging across snow and through flood waters. The Homelite pumps came equipped with small metal skids, but those provided neither enough height nor sufficient bearing area. The system fabricated at CEL for each unit consisted of two runners made from 4-inch aluminum channel attached to upright supports (to which the pumps were bolted) made from 6-inch aluminum channel. In this configuration, the pumps stood nearly 10 inches above the bottom of the runners. The skid assembly for the recoil-pull unit weighed about 15 pounds, while that for the electric-start unit was slightly heavier due to the extra length needed for the battery.

The skids were not altogether satisfactory in the field. The runners were spaced too close together, making the pumps top-heavy and unstable under tow. In addition, post-field trip modifications to the pumps made it necessary to fabricate a new skid system. The new design will be described later in this report.

The two Homelite pumps are equipped with 3-inch-diameter intake ports. It was decided to fabricate the intake plumbing from 3-inch-diameter hose and use an 8-inch-diameter auger to drill the water-access holes through the ice sheet. The 8 inch size was selected since it provided just enough clearance to accommodate both pumps at a single location. One problem anticipated for the field program was the loss of flood waters back down the access holes. To circumvent that problem, two types of hole casing were selected. One type was a 24-foot length of 8-inch-ID concrete (Burke) tube made from 1/8-inch-thick cardboard. In the field, lengths of this material would be cut to size and wedged into the intake holes as necessary. Enough tube height is left above the surface of the ice to permit several floodings. The second type of casing was designed and fabricated from thin-walled aluminum irrigation tubing. It consisted of an 8-inch-diameter outside shell and a 7-inch-diameter inside shell, with foam-in-place polyurethane insulation in between. In addition, electrically traced heat tape was coiled along the inside surface of the outside shell so the casing could be removed as necessary. Enough heat tape was installed so the unit could be melted free from the ice in one hour or less under typical winter conditions. The urethane insulation helped prevent freeze-back of the access hole.

The outlet ports on the Homelite model 120 TP3-1A pump are also 3-inch-diameter male pipe connections. Ultimately, for work on the NDS project, it will be more convenient to use 3-inch hose for discharge plumbing; however, for the field tests it was decided to use an existing inventory of 2-1/2-inch rubber discharge hose belonging to CEL at Barrow.*

The inlet and outlet ports were modified at CEL by the addition of Kamlok quick-connect couplings. Kamlok-type fittings are well suited for field work where sections of hose must be rapidly connected or disconnected. The 10-foot sections of 2-1/2-inch hose at Barrow were already fitted with that type of connection. Each Kamlok connection consists of a male and female fitting. The female is made up of a metallic body, metallic cam arm and rubber gasket; the male is a metallic body only. The Kamlok fittings were ordered with hard-coated aluminum bodies (better strength at low temperatures), stainless-steel cam arms (greater impact resistance against hammer blows which are sometimes necessary when ice forms at the mating surface between fittings), and Buna-N rubber gaskets.

The inlet port entered the pump housing at the front. It was joined to a 6-foot length of intake hose by means of a quick-connect coupling and 90-degree pipe elbow. A 6-foot hose length was used as intake plumbing to provide sufficient emersion depth in the access hole. The outlet port left the pump housing at the side. It was connected to a 90-degree pipe elbow (to change the direction of flow to vertical) followed by several quick-connect fittings that reduced the plumbing to the 2-1/2 inch diameter. The vertical assembly was necessary for changing the direction of flood, since in that assembly there was a fitting that proveded rotation of the discharge hose through 360 degrees. For the electric-start unit that fitting was simply a Kamlok coupling, while for the recoil pump a special swivel joint was tried.

BARROW FIELD TESTS

The CEL field team arrived at the Naval Arctic Research Laboratory, Barrow, Alaska, on 1 March 1977. Shortly thereafter, the Nansen Drift Station Project Office applied to the Department of Natural Resources (Division of Alaska Lands) for a miscellaneous land use permit in order to conduct blasting exercises on the sea ice up to 5 miles offshore. At the same time, NDSPO completed contract negotiations with a Seattle-based blasting firm that was to provide: (1) all materials and equipment required to prepare and detonate the charges; (2) one senior explosives expert, appropriately licensed and with demonstrated experience in

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*It seemed unnecessary to special order hose for the short field tests. Also, in discussions with manufacturers, there is currently extensive research being conducted by the rubber industry to develop improved cold-weather hose, and new products may be available in the near future.

safe handling and application of explosives; (3) a standard operating procedure and a test program for the tests at Barrow; and (4) the post-test report, to include documentation of test procedures, pertinent results, and recommendations.

Successful flood-finishing of a blasted ice obstruction depends on the ability of the explosive charge to both level the formation and at the same time throw debris outward from the area to be finished. Otherwise, final leveling must be done mechanically and/or debris must be pushed away from the blast site by bulldozer or alternate equipment. Either of these conditions would be a problem for runway preparation at NDS; thus, the intended objective for the test program was to obtain information and establish procedures and requirements for blasting ice ridges and hummocks. A number of "shakedown exercises" were planned for the time period prior to the arrival of the blasting team in order to establish some of the operational and flooding characteristics of the pumping system on cleared and uncleared sea ice.

Shakedown Exercises

During some winters, the seasonal ice sheet that grows off-shore from Barrow is extremely smooth and uniform. That condition exists most often when initial "freeze-up" of ocean waters occurs during a period of calm weather. Other years "freeze-up" is followed by stormy weather that fractures and up-lifts the young and relatively thin ice sheet, thereby creating an annual ice covering that is very rough and broken-up on top. Surface conditions during 1977 were somewhat between these two extremes. Although there was no rafting of the seasonal ice itself (just the usual sporadic occurrence of frozen-in chunks of ice remaining from previous year's ice sheet), the surface was nonetheless marked by a high density of shallow disturbances. The amplitude between crest and trough for these disturbances was no more than 3/4 inch at most locations. The snow cover seemed to conform to the ice below so that the scene in general was one of slight but pervasive surface irregularity. Figure 11 is more or less representative of that condition.

During a 2-hour reconnaissance of near-shore ice conditions, the depth of snow was measured at a number of sites. The average snow thickness was 3 to 5 inches. The condition of the snow could best be described qualitatively as very hard and compact. In the past, it has been surface-flooding policy to remove and disperse any snow cover more than 2 to 3 inches unless "temperatures are sufficiently warm so that complete saturation of the snow is achieved with the first application of water" (Ref 6). The fear was that cold, dense snow would resist the penetration of water and would result in something other than a solid flood layer. In other words, there would be a potential for zones of weakness. Also, the presence of snow presents a definite barrier to the spread of flood water. Reduced spread causes ponding, and ponding represents a concentrated load on the ice sheet. However, the problems associated with reduced spread and concentrated loading are pertinent mainly to the type of surface flooding practiced in the past - that is, flooding from stationary pumps operating on relatively thin ice sheets.

The portable pumps developed for the NDS project could be relocated as necessary to compensate for the barrier effect of snow. Besides, the runway preparation would be staged on a pack-ice foundation so that concentrated loading produced by flooding snow should not cause appreciable downwarping or cracking.

Limitations on the availability of heavy-equipment, man-power and time may very well preclude the removal of snow at the Nansen Drift Station; thus, one objective of the field tests was to determine what was required to successfully flood cold, hard snow to a level, flat surface. In particular, it was hoped to see how much area could be covered in a measured period of time, and with what ease. Also, very importantly, it was hoped to see if complete saturation could be achieved.

The two pumps with accessories arrived at NARL on 4 March. After the two units were uncrated and filled with gasoline, they were placed outside to cold soak. Meanwhile, the CEL LGP* D-4 bulldozer was used to clear snow from an approximately 200 x 200-foot test plot on the annual ice about 200 yards offshore. Two days later, when everything was set for the first flood, neither unit would start. The air temperature during that period had varied from a high of -18F to a low of -29F. It was then that both pumps were slightly modified. The recoil-pull unit on the manual-start pump was disassembled, cleaned of grease, and relubed with Polar Start oil. The oiled polyurethane-foam insert was removed from the air cleaner of the electric-start unit. It was replaced by a small 12-volt, diesel-type glow plug which, when shorted across the battery, was used to heat intake air. The following day, after a cold soak at temperatures as low as -30F, the electric-start unit fired following 7 seconds of cranking and 30 seconds of preheat. Exhaust gases from that unit were then used to preheat the second pump until it too fired.

Figure 12 shows the manual-start pump in operation on the test pad. The intake hole was drilled using an 8-inch-diameter auger with a two-cycle gasoline-driven powerhead, and then cased with a 17-inch length of cardboard Burke tube. The intake plumbing was as described earlier. The configuration shown for discharge plumbing was that used for free-flooding near the pumps, and consisted of a 6-foot length of rigid 3-inch-diameter intake hose with vertically oriented swivel-joint/Kamlok network so the direction of outflow could be rotated through a full 360 degrees. Prior to the first lift, the average temperature in the top 2 inches of ice was -25F as measured with a 3-inch-long stem dial thermometer; thus, the surface of the cleared ice sheet was quite cold. It took about one hour of continuous flooding for water deposited in the first lift to back up in spots to the 3-to-4-inch depth desired for many surface-flooding operations. The radius of flood water at that time was approximately 50 feet.

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*Low ground-pressure.

Figure 11. Snow condition offshore from Barrow, Alaska, during 1977.

The following day another lift was added. This time some attempts were made to help encourage the spread of flood water away from the pumps. A 50-foot length of 1-1/2-inch-diameter canvass fire hose with tapered brass nozzle was attached to the discharge of one unit, while the second pump continued to operate as in Figure 12. It was hoped to use the high-velocity water to counter damming along the periphery of flow by knocking down the slushy barriers. The basic idea was fine, but the mechanics of implementation were far too demanding. The high-pressure discharge from the nozzle caused the hose to whip around and "do its own thing" every time the direction of outflow was changed in the slightest. It would be very difficult to move the hose around for useful work under ordinary conditions, let alone in the cold, slushy conditions of the ponded ice sheet. The technique was tried with the nozzle removed, but even then the hose was hard to handle and there seemed to be no advantage in using such a long length. Next the old method of "kicking down" slush ice along the perimeter was tried. It was improved upon by introducing a long-handled wooden "squeegee" that was used to knock down ice dams and push flood waters outward. Those two techniques, however, were labor intensive and should be viewed as better suited to keeping one occupied and well-exercised than to maximizing flood area. This is not to imply that patrolling the flood zone is not useful. It is always good policy to scout the area for high and low spots. Also, when surface flooding is done using stationary pumps, knocking down ice dams is probably the easiest way of redirecting and extending water. However, when portable pumps are available, time is probably better spent in relocating the units.

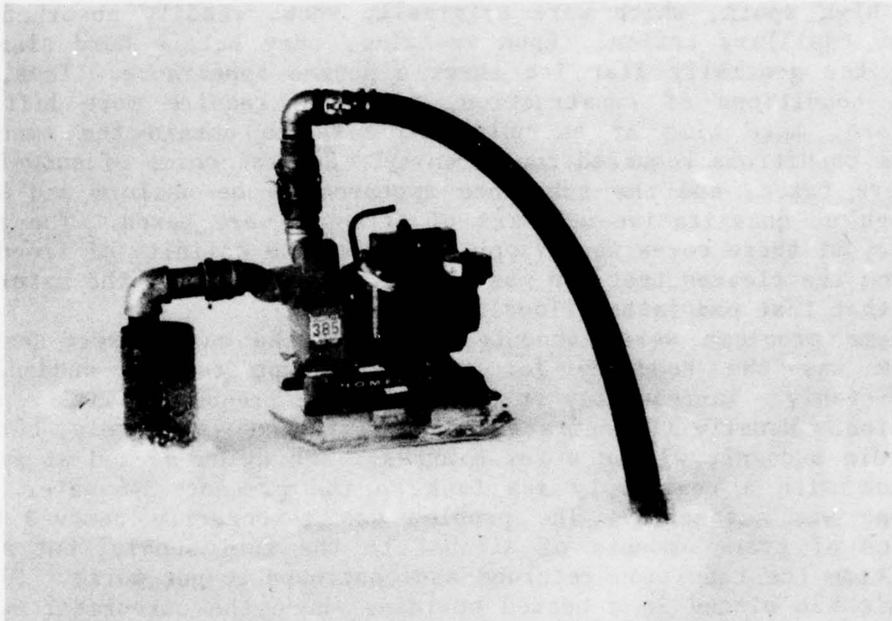

Figure 12. Surface flooding on sea ice cleared of snow.

After a fourth and final lift was deposited on the test pad, the radius of flood was extended to approximately 120 feet. It is important to keep in mind that the discussion so far has referred to a sea-ice test site cleared of snow. The same intake hole was used for each lift and the only discharge configuration used (except for the brief testing of the fire hose) was the 6-foot section of rigid hose.

Flooding was also conducted at another test area where the snow was not removed. At that location, the snow cover on one side of the intake hole was left in its virgin condition, while the other side was walked over by several passes of the LGP D-4 bulldozer. It was hoped to see if cutting the top crust would improve the ability of flood water to saturate the snow. As expected, the presence of snow slowed down and restricted the spread of water and so increased ponding around the pumps. It was necessary to remove the short 6-foot discharge and replace it with sections of 2-1/2-inch-diameter rubber hose; however, just two sections (20 feet) on each pump worked well. Continued flooding showed that, from the standpoint of water penetration, there was little difference between the virgin and trafficked snow; both sides were easily flooded to saturation so that there were no areas of incomplete water penetration. There was, however, a visible difference in surface characteristics. Walking the bulldozer over the one side helped level it by flattening high spots. When it was flooded to saturation, the result was a smooth and uniform surface. The virgin snow, on the other hand, continued to have high spots, even after it was flooded several times.

These high spots, which were originally snow, readily absorbed water through capillary action. Upon freezing, they became hard slush-ice, giving the generally flat ice sheet a pocked appearance. Thus, under actual conditions of construction, it would require more lifts and, therefore, more time at an unleveled site to obtain the smooth-ice surface conditions required for a runway. Several cores of snow-flooded ice were taken, and the substance appeared to be uniform and strong, although no quantitative measures of strength were taken. The average salinity of these cores was 17 ppt. The average salinity of flood-water ice from the cleared test pad was 20 ppt, while that for the natural ice below that test pad (after flooding) was 8 ppt.

Some problems were encountered during the early exercises. One problem was the tendency for the two pumps to die suddenly and unpredictably - infrequently at first but more frequently with continued operation. Usually the units could be restarted immediately, but would again die suddenly within a few minutes. The dying seemed at first to coincide with a near-empty gas tank so the presence of water in the gasoline was suspected. The problem was temporarily removed by the addition of trace amounts of alcohol to the fuel supply, but after a short time the condition returned and continued to get worse. Finally, one unit was placed in a heated building where the carburetor was disassembled. Water was found in the intake manifold. It was suspected that expansion of the intake air (as it entered the manifold from the carburetor) caused some vapor to condense upon the cold metal surfaces where it froze immediately, thus restricting and eventually blocking air passages. To counter that problem, a makeshift exhaust deflector was fabricated to redirect hot gases over the carburetor and intake manifold. The deflector was made by clamping a 90-degree electrical conduit elbow over the muffler and connecting it to a 90-degree pipe elbow, thereby giving an effective change in direction of 180 degrees. Figure 13 shows the configuration. The set-up was effective in greatly reducing the frequency of engine stoppage. After its implementation, there was only occasional power loss, which was due mostly to water in the gasoline (since the condition cleared when alcohol was added).

Another problem encountered in the field was icing. At first it was necessary to thaw intake and discharge plumbing each time a pump was used because of ice build-up in the metallic Kamlok couplings. Even with pre-thawed plumbing, there was usually a marked decrease in flow rate after 2 to 3 hours of the next application. As a result, the Kamlok fittings were insulated by wrapping them with several layers of 1/8-inch-thick, adhesive-backed foam rubber; however, even after doing so, there was still appreciable ice formation. Since the problem remained, on-site thawing was next attempted. One unit was covered as it pumped, and heat was applied using a gasoline-fired Herman-Nelson force-air heater. Instead of increased flow, the result was no flow: the heat melted the outside of the internal-ice shell, creating a free-moving plug. When the plug was sucked into the pump housing, the inlet was choked, and then the engine stalled.

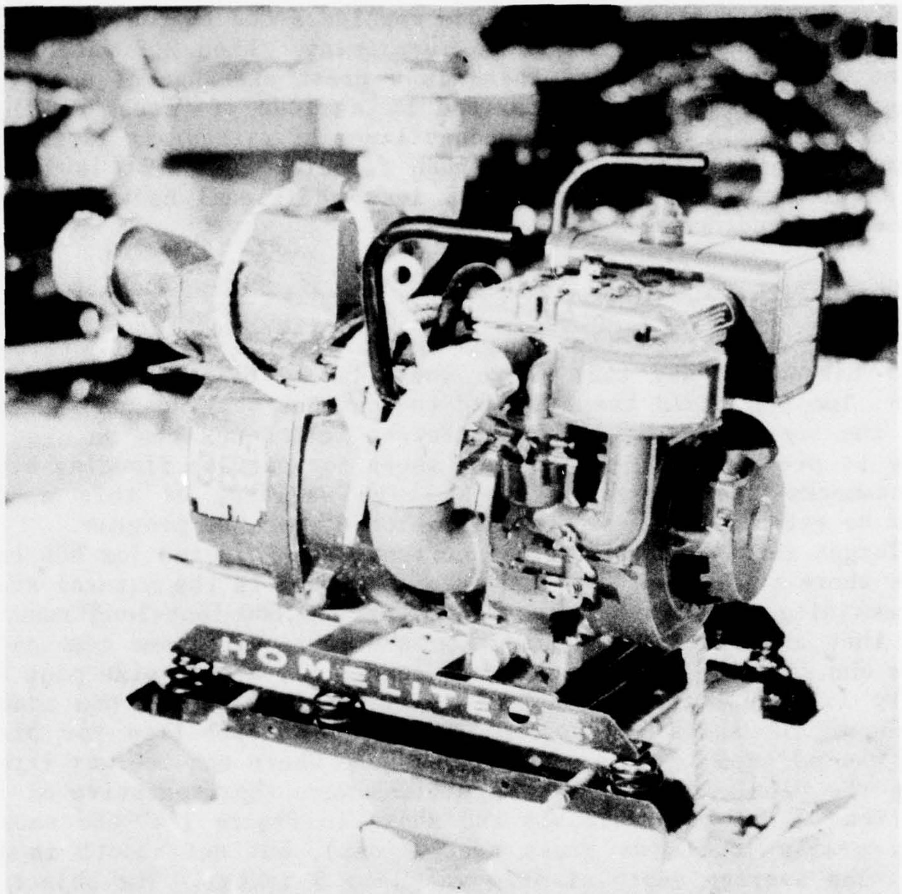

Figure 13. Lightweight centrifugal pump with exhaust-gas deflector.

At the end of one day it was observed that while one pump was heavily iced, the other unit had no ice build-up at all in either the intake or discharge. Both units had been operated in the same manner and for the same period of time, the only difference being their orientation on the ice sheet. The unit with no ice was situated in such a way that the prevailing breeze (less than 10 mph) carried the exhaust gases and engine-cooling air back across the intake and discharge plumbing. As an experiment, the unit with ice build-up was repositioned in the same way. In less than one hour, the pump began to sputter and choke. After the dislodged ice particles were cleared from the inlet and casing, the unit ran well, flow increased, and, by the end of the day, all ice was melted from the intake and discharge. These results seem remarkable in light of the large "cold sink" offered by the ambient environment. Not only did the waste heat prevent ice formation, but it

melted existing ice as well. If one considers the thermodynamics of the situation, however, it is not so surprising. When 29F water comes in contact with very cold air, there is a great exchange of energy. This phenomenon is usually characterized by a cloud of "steam" rising from the ice sheet. In effect, a boundary layer of warmed air is formed over the surface of the flood zone. When flooding equipment is located in this environment, it requires much less additional heating to prevent freeze-up of engine and pump.

Model Runway Preparation

Around mid-March, the Nansen Drift Station Project Office telephoned Barrow to say that there would be no blasting program during 1977.* The CEL field team decided to continue working under an assumption, the assumption being that blasting techniques can be used effectively to prepare an irregular ice sheet for surface flooding by leveling hummocks and pressure ridges. The validity of this assumption should be established prior to initiation of the NDS program.

Target runway considerations currently anticipated for NDS call for a site where at least 80% of the area is usable in the natural state and the remaining 20% can be prepared. For a 5,000-foot-long runway this means that a 1,000-foot-long section should require some combination of repair and finishing. To model that condition, a half-size plot approximately 170 feet wide and 500 feet long was flagged on the annual sea ice about 250 yards offshore. Without the capability for blasting, there was no need to go farther from shore where the ice was irregular. Within the plot, ice and snow conditions were representative of characteristics described previously and shown in Figure 11: the snow cover was generally level (no gross protrusions), but not smooth in appearance. The average depth of snow was 3 to 5 inches. The objective was to treat the test plot as if it were part of a runway site, apply and refine the techniques for flooding snow developed during the shakedown exercises, further define the capabilities of the flooding equipment, and gain some insight into the rate at which construction can take place.

The heated CEL instrumentation trailer was moved to the edge of the test plot, where it was used as a shelter to store equipment and warm personnel and materials. As a first procedure, the LGP D-4 bulldozer was walked (one pass only) over the entire surface area to knock down high spots and more-or-less level the snow cover. (At NDS it may be possible to accomplish the same thing using a tracked vehicle and drag if a bulldozer is not available.) Figure 14 shows a section of the trafficked snow cover.

The first-day surface-flooding effort was conducted over a period of 5 hours. During this operation, each pump was relocated once, thereby requiring four holes to be drilled. The drilling equipment consisted of a small 2-stroke gasoline-driven engine and sections of 3-foot-long, 8-inch-diameter auger. It took two men an average of 2 minutes to drill completely through the 6-foot-thick sea ice. Both pumps operated using

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*The blasting contractor cancelled.

20 feet of rubber discharge hose. Figure 15 shows the electric-start unit in action. By the end of the day an area approximately 150 feet by 270 feet was covered by at least 3 inches of water. In some areas the water was deeper due to ponding, while in other areas there was still a high density of protruding slush-ice. The following day two additional holes were drilled near the unflooded end of the pad, and the first lift was completed in about 4 hours to give a total coverage of approximately 150 feet by 475 feet. Figure 16 shows a typical region of the flood zone after the first lift was applied.

At the beginning of the third day, before starting deposit of the second lift, a containment was placed around the boundary of the model plot to minimize the loss of water across the perimeter. The containment was made from very thin-walled collapsible 8-inch-diameter polyethylene tubing. Figure 17 shows the dike formed by the tubing once it was filled with seawater and allowed to freeze. The second lift was applied in 4 hours using five suction holes. It extended the flood waters on the side to the full 170-foot width between containments, while maintaining the 475-foot length attained during the first lift. The 2-inch average depth of deposit covered most of the snow-ice protrusions that remained after the first lift. Upon completion of the second lift, the model runway section had the general appearance presented in Figure 18.

A final "finishing" lift was deposited the following day. At the time of its application the flood zone was already smooth and level, and warmed appreciably so that the water spread quickly and evenly. Two holes at either end of the pad were drilled, and in 5 hours of flooding a near uniform 3-inch layer was placed on the entire pad. After freeze-up, the site could be best described as a flat, rectangular expanse with few noticeable surface protrusions. Figure 19 shows the surface of the ice as the final lift was being applied.

After construction was completed, level measurements were taken at 15 locations on the test pad and four locations on the annual ice as indicated in Figure 20. The readings were corrected to present the highest point as zero reference. It is interesting to note that although the pad is level (1.3 inches maximum measured height difference), it is elevated 4 to 5 inches above the surrounding ice sheet. Figure 20 also shows three stations where cores were removed to measure salinity. Results for the flooded ice are as follows:

Station	Lift	Core Length (in.)	Salinity (ppt)
A	top	3-1/2	16
	middle	2	17
	bottom	2-1/2	12
B	top	4	18-1/2
	middle	2-1/2	16-1/2
	bottom	3	13
C	top	2	17-1/2
	middle	2	19
	bottom	3	18

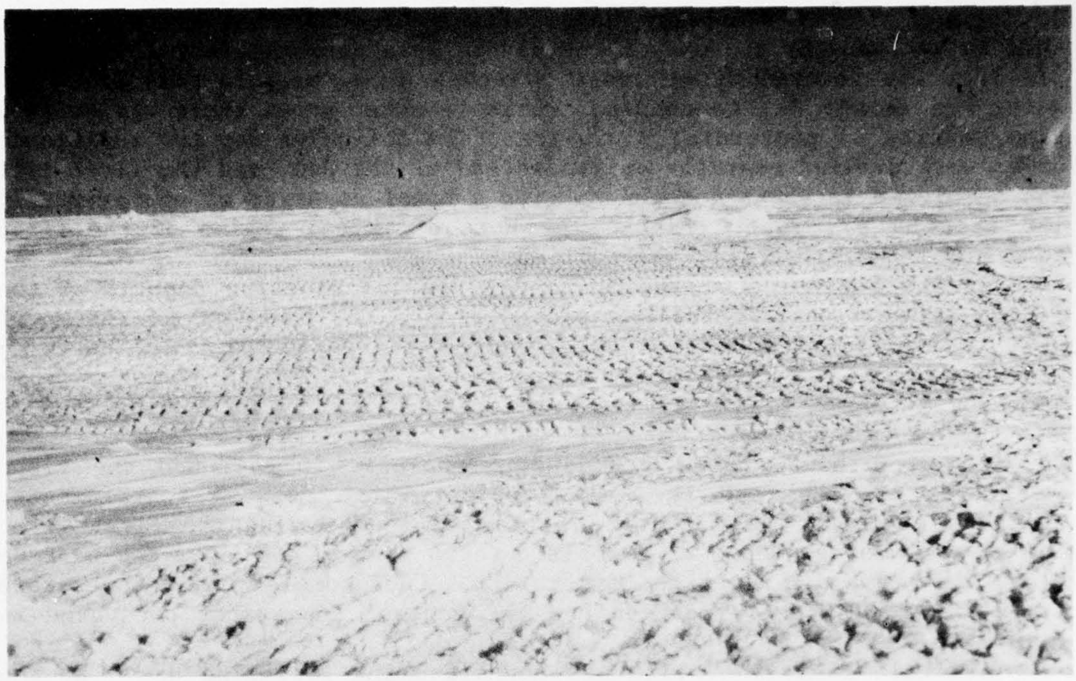

Figure 14. Snow cover leveled with one pass of a LGP D-4 bulldozer.

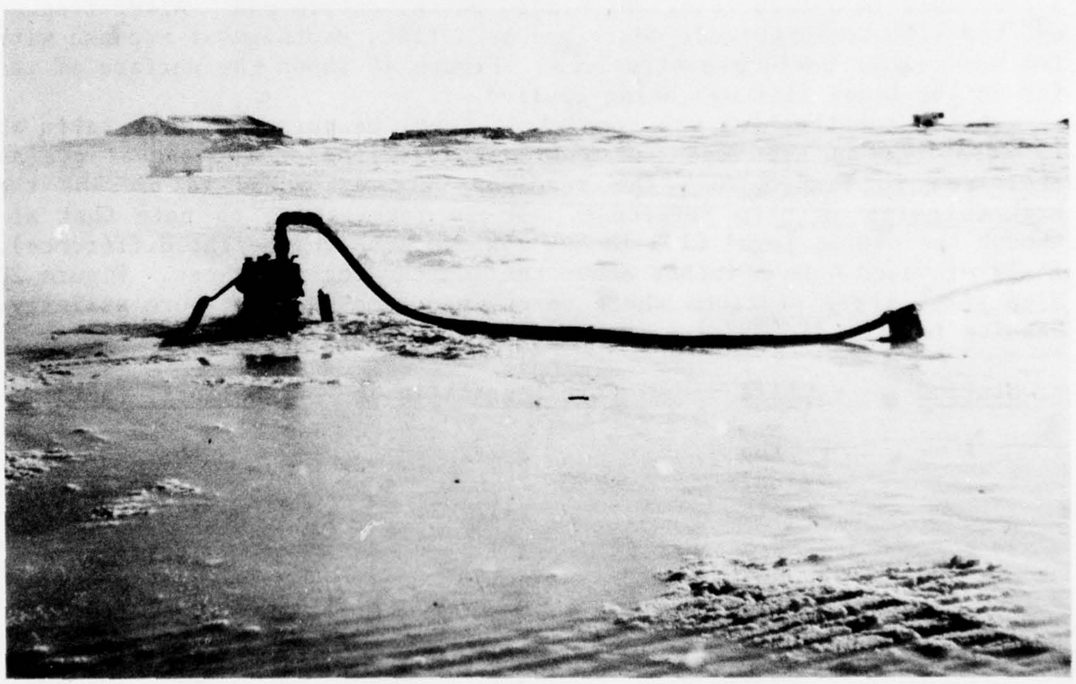

Figure 15. Surface-flooding on leveled snow with electric-start pump.

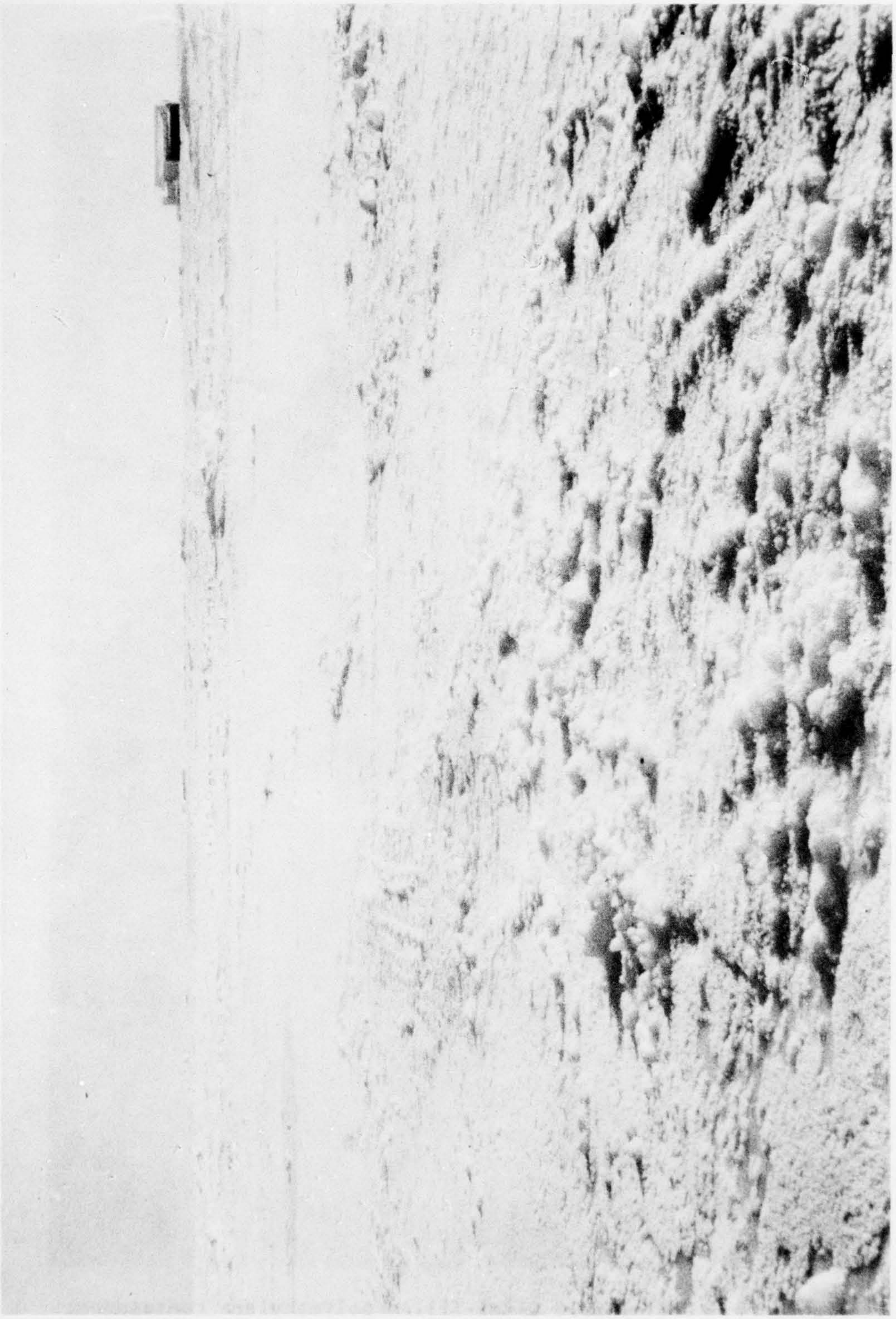

Figure 16. Model runway section after the first lift of flood water.

Figure 17. Collapsible water-filled polyethylene containment.

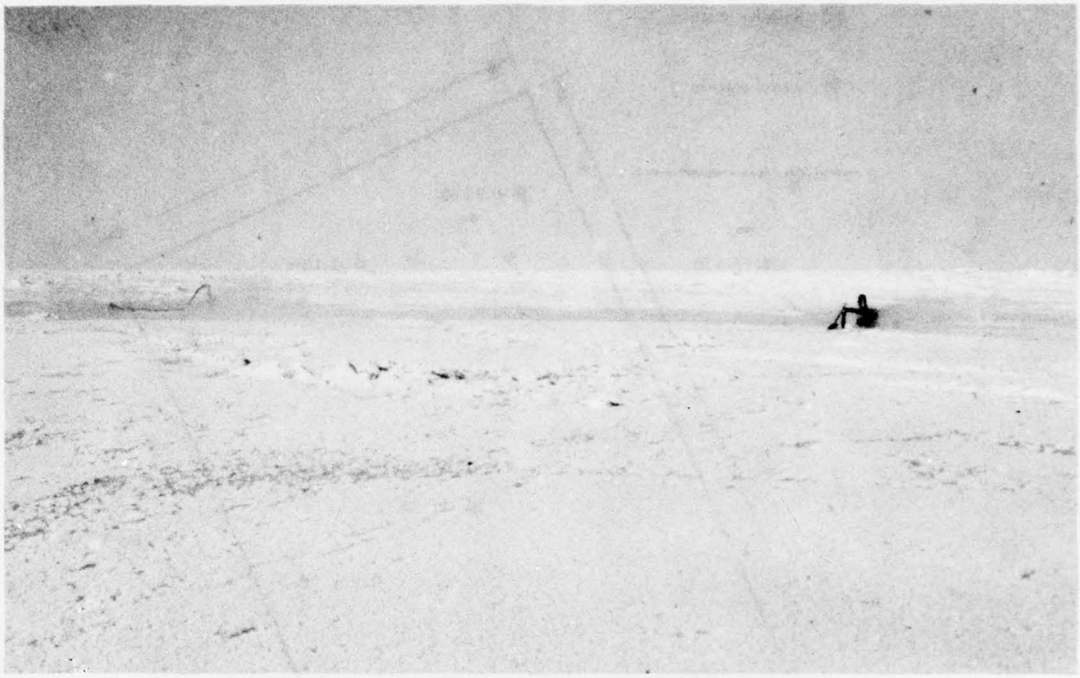

Figure 18. Model runway section after the second lift of flood water.

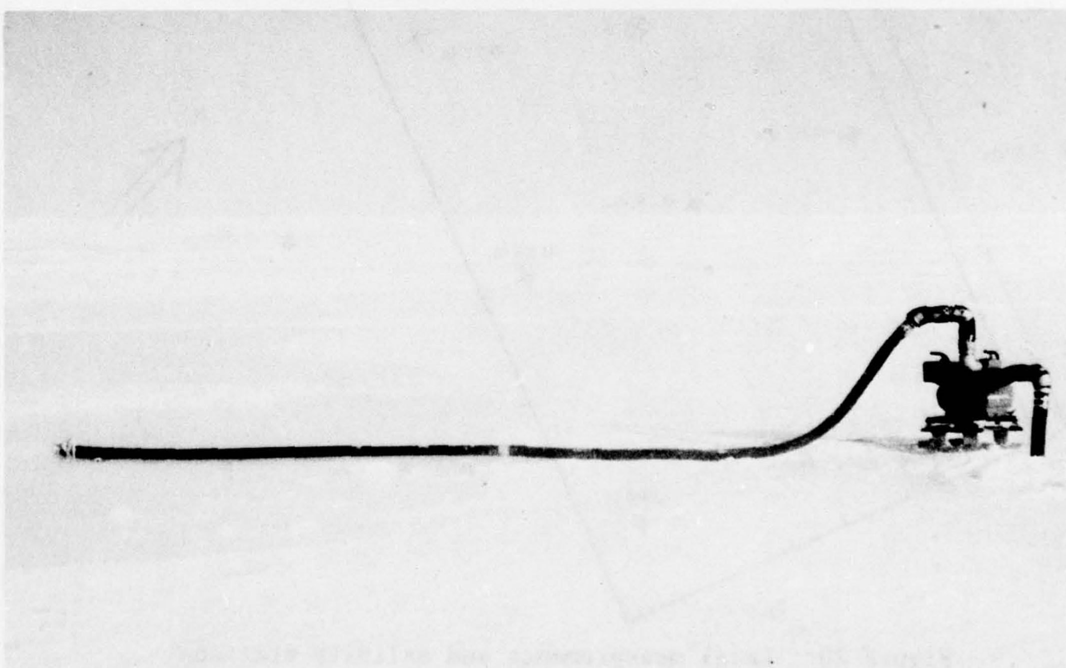

Figure 19. Model runway section during application of the final lift.

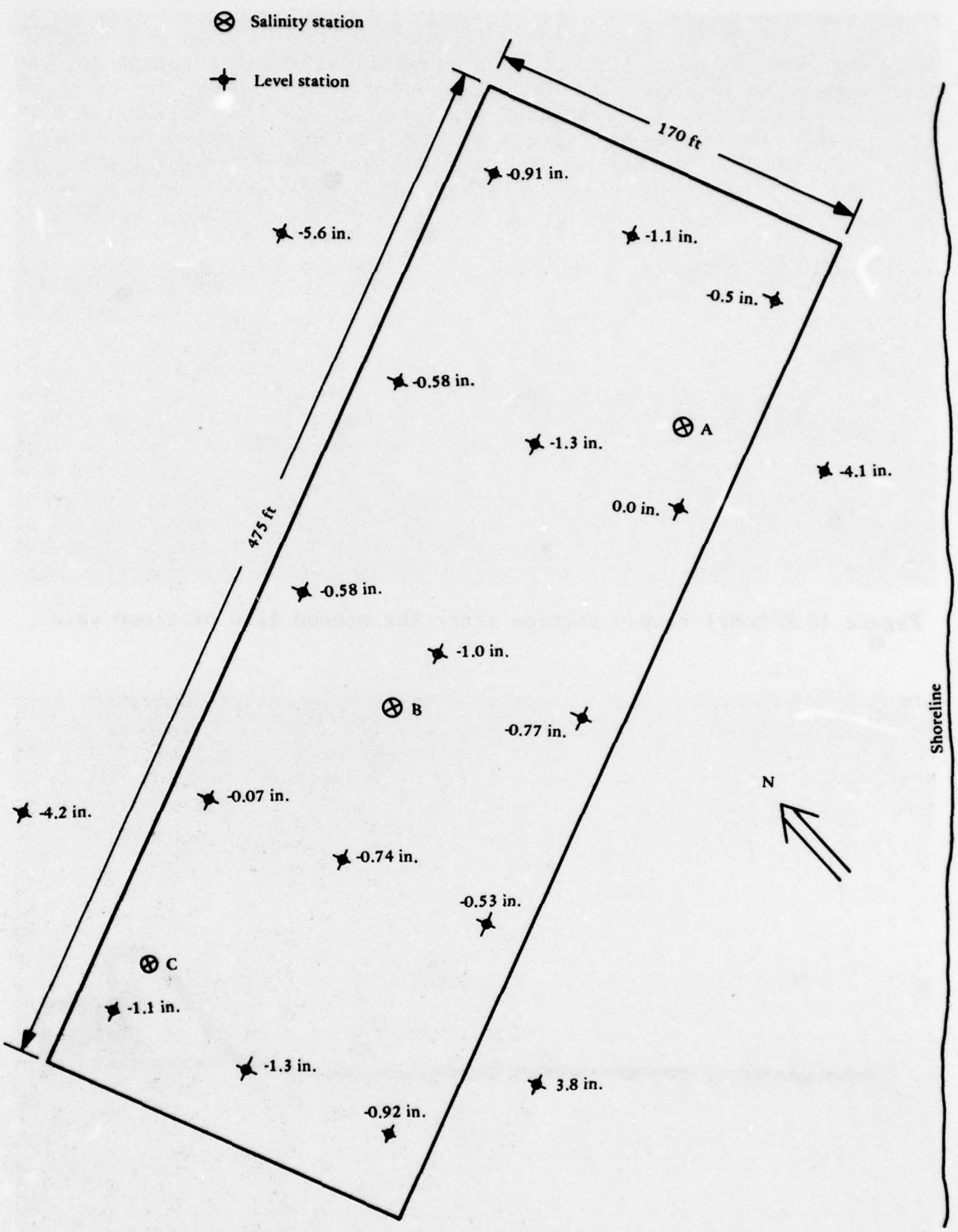

Figure 20. Level measurements and salinity stations.

Discussion

The pump shown in Figure 19 is operating without a casing for the intake hole, a practice followed throughout construction of the model runway section. It was found that serious loss of flood water back down the intake hole could be avoided by (1) locating the pumps on obvious high spots; and (2) using slush drawn up from the hole by auger action to form a natural dam. These techniques helped make it feasible to relocate the pumps frequently, but there were also problems that made relocation more difficult. One problem involved movement through the flood waters. Actually, there was little problem during the second and third lifts, because the deposited material remained as a liquid for some time. However, during the first lift (when pumps require most frequent relocation) the slush produced from saturating the snow was very viscous, and, as a result, it tended to become impacted in, and frozen to, the skid assembly. The problem was greatest for the electric-start unit because it was heavier and would also be more easily packed with slush around its battery and generator. At times it took both members of the field team to drag the pump from one hole to the next. Also, the skid design was deficient in that the runners were too closely spaced together, thereby making the units top-heavy and easy to turn over. To help counter those problems, new skids are being built from thin-stock aluminum. The bottom of each skid will be wider for increased stability, and the skid will consist of a single full-width, full-length runner that is curved upward in the front to assist movement through flood waters.

One additional change should be noted at this time. After the equipment was shipped back to Port Hueneme, the manual recoil-start pump was refitted with a 12-volt electric starter-generator similar to the one installed on the other pump. In the opinion of the field team, the extra convenience and versatility gained from electric starting more than compensated for the increase in weight and decrease in portability.

CONCLUSIONS

In the past, surface-flooding activities have been confined to areas near major military logistic centers. As a result, the techniques developed for sea-ice runway construction have relied extensively upon the use of heavy equipment to clear snow and position large stationary pumping equipment. At remote sites, such as that planned for the Nansen Drift Station, requirements are different. The construction crews will be severely restricted as to their size and number of support equipment available, and they may be required to work concurrently at a number of scattered locations.

The field-test program conducted by CEL at Barrow, Alaska, during March 1977 added a new dimension to surface-flooding technology. A 170 x 475-foot model runway section was constructed by two men flooding an average of 4 to 5 hours each day for 4 days. Those exercises demonstrated the feasibility and capability of using small, lightweight pumps

to *prepare sections of a sea-ice runway.* The high portability of the units makes it possible to relocate them frequently and to successfully flood over the natural snow cover.

Several techniques were devised to help guarantee the continuous start-up and operation of unsheltered, unheated pumps in the cold. These techniques included: (1) use of a glow plug to preheat the electric-start unit; (2) use of the exhaust gas from the electric-start pump to preheat the manual-start unit; (3) redirection of the exhaust gas toward the manifold and carburetor; (4) orientation of the pumps so that the exhaust gases and cooling air can blow across the intake and discharge; and (5) full-throttle running of pumps (with intake and discharge disconnected) to warm the water in the casing prior to shutdown and draining.

RECOMMENDATIONS

The following recommendations are in response to problems that may be encountered during deployment of the Nansen Drift Station.

1. During the CEL field effort, no time was required to prepare explosive charges or remove rubble from a blast area. It is highly recommended that research be conducted on polar ice to determine the effectiveness of explosives in (1) leveling a surface ice obstruction, and (2) throwing debris away from the blast zone. Both results have an important influence on the ability to use surface flooding as a finishing technique.

2. The CEL field team was able to develop techniques for successfully flooding an area covered by 3 to 5 *inches of cold, hard snow.* It is anticipated that these same techniques can be extended to construction at NDS; however, surface conditions in that region of the Arctic are much less defined. It is recommended that a more detailed reconnaissance of the projected travel path be conducted prior to the onset of drift to establish typical snow-cover characteristics. It is further recommended that the research platform be equipped with a lightweight bulldozer or alternate tracked vehicle capable of leveling snow and moving snow and blast-ice debris.

3. The CEL field team was able to chose the time to test. March in Barrow is a period of the year when the sun shines about half the day, thereby making it easy to work but yet have subfreezing temperatures. As one travels farther north, one finds long summers with 24 hours of daylight followed closely by long winters with 24 hours of total darkness, and a short interval between during which the sun rises and sets. Obviously, darkness makes both working on the ice and flying difficult. On the other hand, constant daylight produces surface deterioration of an ice runway by solar insolation, and it usually means warmer air temperatures that will restrict surface flooding. Thus, in all likelihood, there will be substantial surface flooding during the periods of

darkness. It is recommended, therefore, that different systems of lighting be investigated and tested contingent upon projected resupply scheduling.

4. Since there is as yet no master plan for overall implementation of the Nansen Drift Station program, it is difficult to project what level of manpower and equipment will be available for support functions. However, one can make a few generalizations regarding surface flooding. At this time, the resupply effort is envisioned to be a very important, but periodic event. It may be necessary on a short-term basis to enlist as large a work force as possible and dedicate long hours to runway preparation. Thus, it is important that an adequate number of pumps and other surface-flooding equipment be maintained and ready to go. Also, although only a projected 20% of a 5,000-foot runway is expected to require repair and/or finishing, the individual work sites may be scattered. It would be good if enough components were available to work several locations simultaneously. Finally, contingencies must be made for the maintenance, breakdown and repair of pumps. All of these considerations reinforce a recommendation that as many as 10 to 12 water-handling systems be provided for surface-flooding operations near the Nansen Drift Station.

ACKNOWLEDGMENT

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REFERENCES

1. National Research Council, "Scientific Plan for the Proposed Nansen Drift Station," Committee for the Nansen Drift Station, National Academy of Sciences, Washington, D.C., 1976.

2. Bureau of Yards and Docks. Technical Publication Navdocks TP-PL-16: Sea ice bases. Department of the Navy, Washington, D.C., Jan 1955.

3. Department of the Air Force. Manual No. AFM 86-5: Ice Airfields. Washington, D.C., Sep 1958.

4. Naval Civil Engineering Laboratory. Technical Report R-185: Point Barrow trials, FY 1959: Investigation of thickened sea ice, by J. E. Dykins and A. I. Funai. Port Hueneme, Calif., Apr 1962.

5.________. Technical Report R-218: Point Barrow trials, FY 1960: Free-flooded and ice-aggregate fill, by J. E. Dykins, N. S. Stehle and K. O. Gray. Port Hueneme, Calif., Nov 1962.

6.________. Technical Report R-511: Ice construction - Methods of surface flooding, by C. R. Hoffman. Port Hueneme, Calif., Jan 1967.

7.________. Technical Report R-189: Sea ice engineering, summary report - Project Ice Way, by W. D. Kingery, D. W. Klick, and J. E. Dykins. Port Hueneme, Calif., Sep 1962.

8.________. Technical Report R-402: Ice construction - Survey of equipment for flooding, by C. R. Hoffman. Port Hueneme, Calif., Jan 1966.

9.________. Technical Note N-727: Ice construction - Prototype submersible electric pump and extension tube, by C. R. Hoffman. Port Hueneme, Calif., Oct 1965.

10. Civil Engineering Laboratory. Technical Note N-1376: The man-made McMurdo ice wharf - History, construction and performance, by J. L. Barthelemy. Port Hueneme, Calif., Feb 1975.

11. Barthelemy, J. L. "Construction of a Surface-Flooded Ice Wharf," in Proceedings of the Second International Symposium on Cold Regions Engineering. Department of Civil Engineering, University of Alaska, Fairbanks, Alaska, May 1977.

12. Civil Engineering Laboratory. Technical Report R-811: Ice engineering - Quantification of subsurface ice-thickening techniques, by J. L. Barthelemy. Port Hueneme, Calif., May 1974.

13. Adams, C. M., D. N. French, and W. D. Kingery. "Solidification of Sea Ice," in Journal of Glaciology, vol 3, no. 28, 1960.

14. Pounder, E. R. Physics of Ice. Oxford, England, Permagon Press, 1965.

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